

The AMSAT[®] Journal

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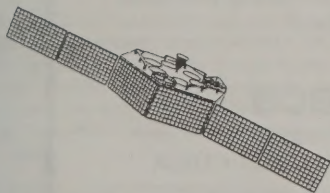
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AMSAT-DL President and Phase 3D Project Leader, Dr. Karl Meinzer, DJ4ZC (R) and AMSAT-NA VP Engineering Dick Jansson, WD4FAB, (L) share a light moment at the Marburg, Germany train station while enroute to final Phase 3D launch negotiations with European Space Agency officials in Paris, France. The following article written by Jansson, presents the mechanical and thermal design of Phase 3D. This article was originally presented at the AMSAT-NA 13th Space Symposium and Annual Meeting held October 1995 in Orlando, Florida. (AMSAT-NA Photo by Keith Baker, KB1SF)

Mechanical and Thermal Design of the Phase 3D Spacecraft

By Dick Jansson, WD4FAB (wd4fab@amsat.org)

Space satellites performing missions varying from (these days) the mundane to the exotic, all have one thing in common - a spaceframe structure. Despite all of the sophisticated technologies that may be involved in the payload packages contained in the spacecraft, the

[continued on page 4]

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Apogee View

By Bill Tynan W3XO

It has now been more than 26 years since the founding of the Radio Amateur Satellite Corporation, or AMSAT for short. Early-on it was decided that we should have some sort of *Life Membership*. The original dues for this category of membership were established as \$50, ten times the annual dues rate at the time. Later, as dues had to be increased to provide more services and keep up with the ever-increasing cost of postage and printing, the life member multiple was raised to twenty times the annual rate. This was in line with the policy of the American Radio Relay League and other organizations. It also reflected a more realistic approach to covering the expenses inherent in supporting the life members with the income realized from reserves that were put aside from the dues they paid in.

However, since many of our life members paid far less than the current U.S. Life Membership rate of \$600 (twenty times the annual U.S. dues rate of \$30), the reserves set aside when they became life members, do not cover the current cost of maintaining them. This is particularly true in the light of our maintaining the current dues rates despite the new, higher, postal rates.

However, we have a contract with our life members and we do not intend to renege on it. Nevertheless, something must be done if we are to maintain our financial viability. While the results of recent Phase 3D fundraising efforts have been very gratifying (more on that later), these monies are for the Phase 3D Project, not for the continuing support of AMSAT-NA. One of the problems we face is that we are continuing to send *The AMSAT Journal*, as well as other mailings, to those who are no longer interested or may have departed this worldly scene. Our agreement was to service the life members for their life, not ours! In order to determine which life members are still interested in participating in the affairs of the organization, we will soon be sending letters to each life member asking for a show of interest. If the person indicates that he or she is not now interested in amateur space activities, we will keep him or her on the rolls but suspend mailings of *The AMSAT Journal*, as well as other information other than the annual ballot for Board of Directors elections. We are required to send ballots to all current members. Of course, if we receive valid evidence of the death of a life member, we will remove that person from our rolls and stop sending all mail.

But, it won't stop there. We intend to ask each life member to make a voluntary annual contribution of one half of the normal dues. There will be no requirement that they make such a contribution. If they do not choose to do so, they will continue to receive all normal mailings, including the Journal. But those who do choose to help, will be contributing to the future financial stability of the organization that has done so much to put Amateur Radio in space.

Won't you help in this process of updating our life member rolls by letting us know of any members you may be aware of that have passed away. Don't be afraid to make an error here. We will run a separate check on each person named. Please contact Martha at the AMSAT office with any information you may have.

I promised a rundown on recent Phase 3D fundraising initiatives. The Hoover Foundation's promise to match all contributions from last June until the end of the year up to a total of \$50,000 was responsible for the best results yet. During that period, our fundraising activity resulted in the raising of a total of over \$106,000. Although this far exceeds the amount that the Hoover Foundation agreed to match, Herbert Hoover III W6ZH, has informed me that all of it will be matched. I think that everyone will agree that W6ZH and the Hoover Foundation have given Phase 3D a very significant boost. It is difficult to thank him, and the foundation he represents, enough.

There was also a \$10,000 donation from the Downing Foundation and \$15,000 from a foundation which wishes to remain anonymous as well as \$1,000 from the Stoner Foundation run by Don Stoner W6TNS.

Fund raising activity from abroad has produced very positive results as well. From Great Britain, \$76,580 has been sent our way from the AMSAT-UK Phase 3D fund. And, AMSAT Italy has sent \$1,000 to help in the effort.

However, despite these successes, we continue to look for additional sources of funding to guarantee the completion and launch of the Phase 3D spacecraft. If there is sufficient money available after the satellite is built and tested, the purchase of launch insurance will definitely be pursued. So, no money will go to waste. (We will run a list of Phase 3D donors in the next issue.)

Thanks to all who have helped make 1995 such a successful year for Phase 3D. We can all hope for great things in 1996. ■

[MECHANICAL, Continued from pg. 1]

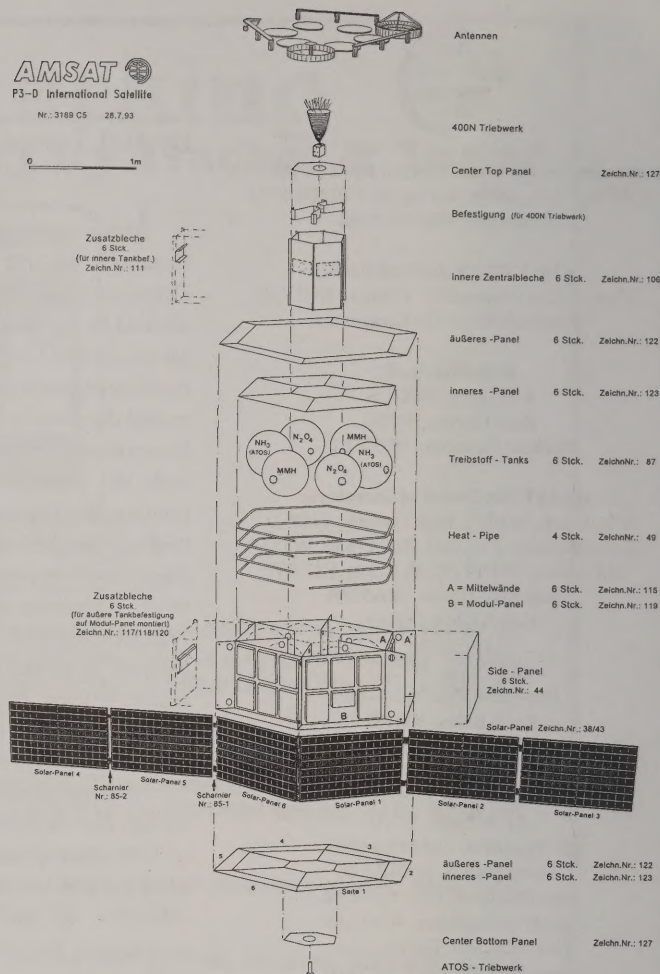
spaceframe technology is well-founded Mechanical Engineering practice based upon aircraft and airframe experience. This does not mean that innovative designs and fabrications are not used, quite the contrary, they are essential. The designer is forced to employ methods that are sound, but less conservative than might be used for some terrestrial object.

The paramount consideration is, however, that of smoothly blending the mechanical-design-technology needs of the spaceframe with all of the other technologies that comprise the complete object and achieves the goal of a successful satellite fulfilling its mission. While this article will deal mostly with the Mechanical Engineering aspects of the Phase 3D spacecraft, the observer must keep in mind that none of this is done out of the context of all of the technologies involved in the whole mission.

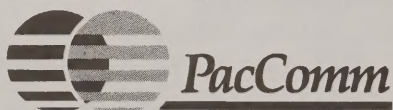
Spaceframe and Launch Adaptor

The Phase 3D electronic equipment must be housed in something. That something is the spaceframe. In the case of Phase 3D, those designing and building the structure were continuously learning new techniques for such fabrications and getting quite an education in the process. Along the way a number of quite good lessons on light-weight aircraft structural construction methods were learned. While the end product is not as light as some would have liked (about 60 kg), it has already demonstrated itself to be very strong. The spaceframes for OSCARS 10 and 13 weighed only 7 kg.

The Phase 3D spaceframe is principally fabricated of thin-gauge sheet aluminum. Its formation, to rather unusually close tolerances for sheet metal structures, caused more than passing



Phase 3D Breakaway Diagram (AMSAT-DL)



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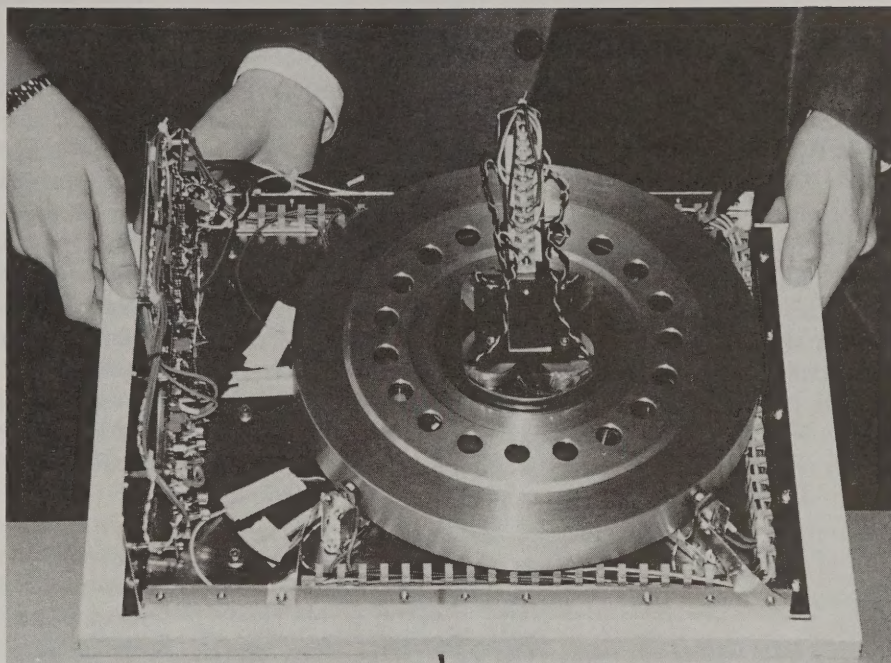
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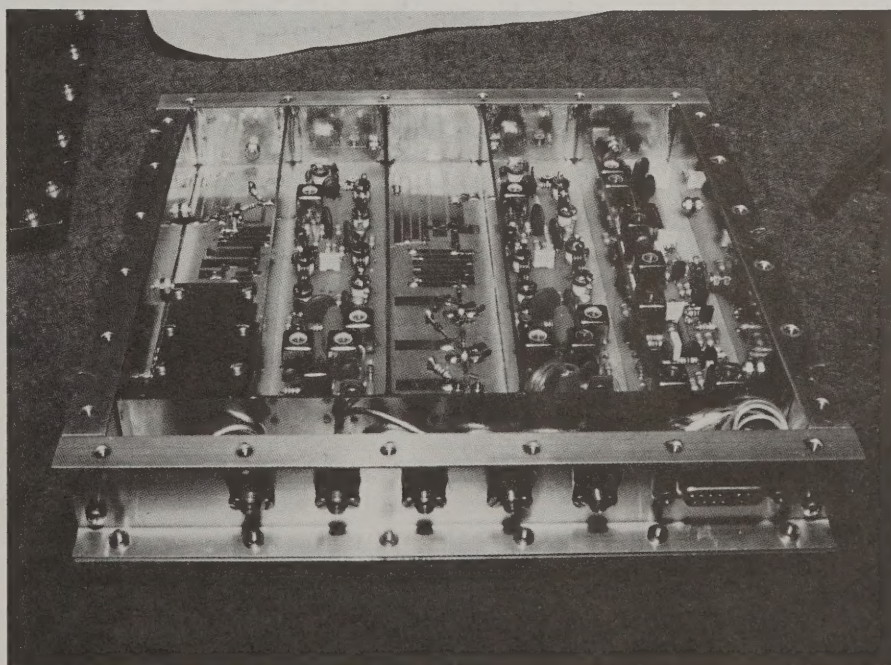
tolerances are in the range of 0.2 mm (0.008 in.). The secret to this type of construction is to place all of the load stresses into the shear plane of the sheet metal, where it is notably strong for its weight. An example of this is the six Divider Panels, one on each corner of the spaceframe. Three of these will be anchored to the launch vehicle which will get Phase 3D into space. Thus, during launch, these three points will be quite heavily loaded in all motions. The only machined parts in the spaceframe are the six Corner Posts at the outer ends of the Divider Panels. These must be robust enough to carry all of these launch thrust loads into the spaceframe, translating all of those forces into the plane of the 0.8 mm thick sheet-metal Divider Panels as sheer forces. It is difficult to completely convey these concepts in words and pictures, but those seeing the spaceframe in-person will be able to more readily grasp the concepts employed in the design.

Working with panels of this type is not all that easy when it comes to mounting massive single elements, such as an 11.5 kg battery assembly. As such mountings are done to the flat surface of a Divider Panel, the panel will flex and bend at the slightest of influences, such as vibration. Such a mounting really needs to have its natural resonance frequency greater than 100 Hz, but without any modifications, such a panel resonance is less than 20 Hz. We found that by using light-weight aluminum stiffeners, formed into the shape of a hat, that we could bring the panel resonance up to 38 Hz. By placing a thin aluminum panel across the tops of the several stringers, we formed an aluminum sandwich, much like a honeycomb panel, and the resonance of the battery mass went up to 128 Hz. All of this added structure was done on the assembled spaceframe (not an easy way to do such a task) and joined with both rivets and epoxy bonding agents. Co-bonding structures like this is a very messy process.

Mention was made above of panel resonance frequencies. We did these tests in a manner that is one of the *flagstones* of AMSAT practice. The method, learned and *borrowed* from our German compatriots, employs a high fidelity amplifier (a 45 year old Ultra-Linear Williamson amplifier) and a speaker held inside of the spacecraft propellant bay. By driving the amplifier with a sine-wave signal generator, the frequency was swept over the range of interest. On thin panels a light object, like a screw washer, will dance with panel resonance. Massive objects, such as the simulated battery, will not respond as well and required another method. This time we used an old ceramic microphone element attached to the *battery* and



First engineering prototype of a Phase 3D reaction wheel built by AMSAT-DL with help from graduate students at the University of Darmstadt, Germany, as part of their master's degree thesis requirements. Once in orbit, Phase 3D will use three of these wheels to keep the spacecraft's high gain antennas constantly pointed towards Earth. (AMSAT-DL Photo)



Flight model 2.4 GHz and 5.6 GHz receivers built by Matjas Vidmar, S53MV for the Phase 3D satellite. The 5.6 GHz hardware is on the left side of the module, while the second of two 2.4 GHz receivers is shown in the middle. Common IF hardware occupies the far right side of the module. (AMSAT-DL Photo)

observed the output signal on an oscilloscope. Resonance frequencies are readily observable with such simple instrumentation. This is AMSAT.

SBS

Since Phase 3D will be a secondary payload on an Ariane launch vehicle, it must conform to whatever space the European Space Agency (ESA) can make available. ESA has the conical 1194V Adaptor which interfaces between the $\phi 2624$ mm ($\phi 103.3$ inches) diameter bolt circle on the Ariane upper stage to a $\phi 1194$ mm clamp-band used for payloads. Although hollow, the conical adaptor does not provide sufficient space to house Phase 3D, or any other reasonably sized payload. Accordingly, ESA offered the amateur satellite community the opportunity to launch aboard the new Ariane 5 vehicle if we would provide a cylindrical *spacer* that could be mounted between the $\phi 2624$ mm diameter bolt circles on the bottom and the conical section on the top. Phase 3D could then ride to orbit inside this cylinder while a prime payload satellite would attach to the conical adaptor with the $\phi 1194$ mm clamp-band. Thus, they require that our cylindrical section must be able to support the launch loads of this prime payload fellow passenger. This means that this AMSAT-provided $\phi 2624$ mm diameter Specific Bearing Structure (SBS) must be able to withstand the load forces imposed by a 4.7 T (metric ton, 10,350 lb.) satellite load. In order to assure ourselves that our design is capable of handling such a load, extensive structural Finite Element Analysis (FEA) computer work has been performed (on the same home computer used to accomplish the thermal analysis).

Construction of two of these SBS units has been completed in Utah, mainly at Weber State University. Each of the \$10k machined flange rings, or Frames, on each end of the SBS cylinder was done in Florida, obviously on a very large lathe. These were made from the highest quality of ring-forged aircraft aluminum. The Frames were mounted to a purpose-built precision steel table, holding flatness and roundness values to less than 0.05 mm (0.002 in.), far better than ESA requires. The 4mm thick sheet aluminum rolled shell sections are attached to the Frames with a total of 976 special fasteners. A total of 2600 additional rivet fasteners are also used in each assembly.

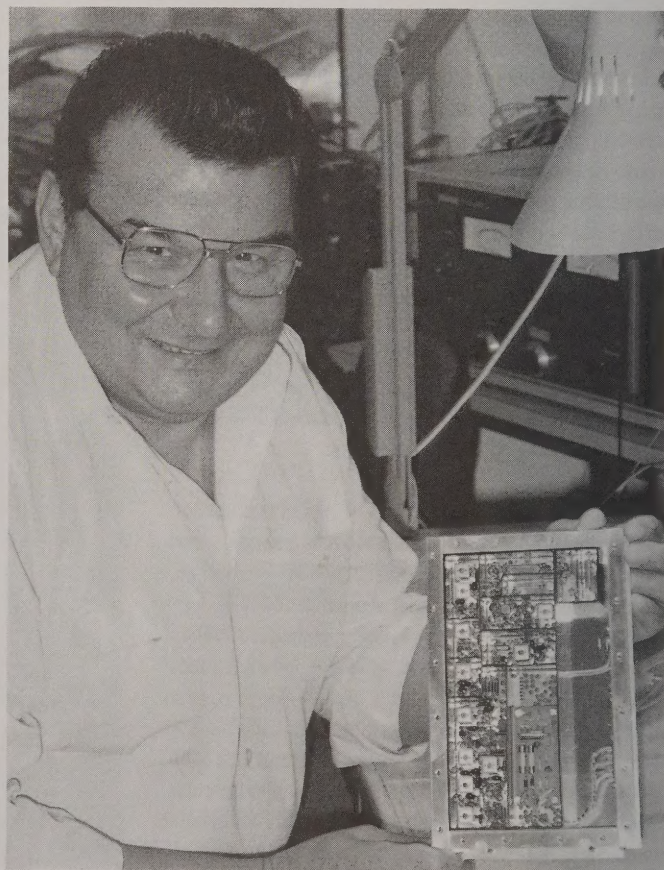
Tests have been conducted at Weber State University to verify the operation of the mechanism to separate the spacecraft from the SBS, and the launch vehicle. For this purpose, a 500-kg Mass Mockup Unit (MMU) was constructed to take the place of the P3D satellite. The Separation Nut units were operated using Nitrogen gas, rather than the pyrotechnically-generated gas sources that will be used in flight. In this manner, we could reuse the Nuts over a number of tests. After a little travail at the start of the tests, all went very well over quite a number of repeated tests, with concurrence of the three Nut separations being within 3 ms (0.003 second) of each other. Witnessing the exiting of a 500-kg object from the SBS was impressive, to say the least!

Thermal Control Subsystem

The three axis stabilization satellite operation planned for Phase 3D drives the thermal design of the spacecraft. Most of the commercial communication satellites spin in order to keep any side from getting too hot and the opposite side too cold. Once in its

desired orbit and orientation, Phase 3D will not spin, but will be oriented in three-dimensional space, with the antennas continually facing Earth. This continual attitude adjustment, with one side facing the sun, causes some interesting thermal design problems. The Phase 3D solution devised to overcome most of these problems is through the use of the four heat pipes. A heat pipe is a thermal linkage of very high conductivity consisting of a closed, evacuated tubular chamber with walls lined with a wick and partially filled with a pure fluid. The fluid used in Phase 3D is anhydrous ammonia. The fluid is vaporized at the hot end. The vapors then move through the hollow core of the tube, and condense at the cold end; from which the resulting liquid is returned through the wick to the hot end by capillary action. By this process, heat is transported from the hot to the cold end. Heat pipes typically offer heat transport characteristics that are many times greater than the heat transfer capability of the best heat conducting materials, while maintaining an essentially uniform temperature. The process requires no power and operates to its maximum performance in a zero-gravity environment.

In the case of the Phase 3D spacecraft, the internal ring-shaped heat pipes remove heat from one part of the spacecraft and re-distribute the energy to other parts where it is ultimately transported through the sides of the spacecraft and radiated to space - the ultimate *heat sink*. What is felt to be a unique feature of this heat pipe system, as employed on Phase 3D, is that none of the pipes come in direct contact with space-facing panels. Instead they depend upon indirect re-radiation of the heat from internal equipment mounting-panels to side panels that are deliberately



AMSAT-DL Vice President Werner Haas, DJ5KQ, pauses at the AMSAT-DL lab in Marburg, Germany to pose with the fruits of his labor...the flight model 70cm exciter for Phase 3D. (AMSAT-NA Photo by Keith Baker, KB1SF)

allowed to become cold. All along, however, the electronic equipment modules maintain their desired temperatures because of the thermal influence of the heat pipe system, regardless of whether those modules are mounted on the solar-heated side, or on the space-cold backside of the spacecraft. These design concepts put to practice the concepts of energy conservation, eliminating any need for active thermal control or supplemental heating.

The earlier Phase 3A, B and C satellites employed several multi-layer thermal insulation blankets to assist these spacecraft through the thermal rigors of spaceflight. Quite simply, such blankets are a first-class nuisance to fabricate, as the required assembly technology is very exacting. In the case of Phase 3D, the side panels of the spacecraft will be painted to provide the necessary radiative heat rejection. The top and bottom panels will be mostly solar energy-absorbing metallic finishes of several different types, depending upon the location and desired temperatures of that section of the spacecraft. In general, the thermal design calls for the mean spacecraft temperatures to be between -5° and $+20^{\circ}\text{C}$ for the expected range of sun angles (β) from -80° to $+80^{\circ}$.

Extensive computer thermal analyses of the Phase 3D spacecraft have given us a very comfortable confidence that this design will provide the desired results, without the use of the kind of thermal blankets used on most other satellites. These thermal analytic computations were accomplished on a home computer to produce a series of temperature performance curves as functions of β angle.

More Power Needed

One of the design features intended to make Phase 3D more accessible to smaller ground stations will be the use of higher power transmitters. This increased power carries with it another set of problems. First, the power must be generated. This means more solar-array area. To achieve this, Phase 3D will employ four deployable solar panels in addition to the two mounted on the spaceframe. This will be the first use of deployable panels on an amateur satellite. Of course, deployable panels means mechanisms to initiate the unfolding plus appropriate hinges and latches to achieve the desired final configuration. The type of hinge used must be able to swing both ways but always return to the desired center position. One of the German members of the Phase 3D Design Team first suggested the use of this type of hinge, and actually obtained one at a hardware store to demonstrate the utility of the principle on the model of the former Phase 3D *Falcon* spacecraft design. As there is not the luxury of a lot of excess space around the current Phase 3D spacecraft when installed in the SBS, this hinge design had to go through several gestations in order to achieve the desired device in a compact manner. This effort included finding a spring wire able to withstand the metallurgical and thermal rigors of anticipated operation at temperatures as low as -100°C .

Power System

Since satellites must get their primary power from the sun, the only practical means of obtaining power is the use of semiconductor solar panels. Generating the power needed to support the transmitters aboard Phase 3D requires large solar panels. The design which evolved calls for a total solar panel area of 4.46 m^2 (48 ft^2) and BSFR Silicon solar cells of 14.3% efficiency. This array

will produce about 620 Watts of power at the beginning-of-life (BOL) and at optimum sun angle ($\beta=0^{\circ}$). After 10 years in orbit, this power number will still be about 350 Watts at a $\beta=45^{\circ}$. This amount of power is still sufficient to operate at least two transmitters and the other necessary spacecraft systems. Like almost anything else, solar arrays deteriorate with age. This is why their performance after a specified number of years is an important design consideration. The cells for Phase 3D are being obtained through a very attractive agreement with DASA, the German Space Agency. These cells are of US manufacture and were surplus inventory from a prior satellite program. While other sources and configurations of solar cells were considered, it was concluded that this one represents the best trade-off between performance and cost. Solar cells, and their assembled panels, represent one of the single highest cost items which go into building a spacecraft.

While solar panels are satisfactory as a sole source of power, some form of energy storage must also be provided. This is accomplished with a battery. Energy storage is necessary, not only to power the spacecraft during times that the sun is eclipsed by the earth, but also to operate the arc-jet thruster. Its power requirements exceed the capability of the solar arrays, even under the best of conditions. Actually, the Phase 3D satellite will carry two batteries, a *main* and an *auxiliary*. This is to provide redundancy in case of failure of the main battery. The Phase 3D design team evaluated several sources and types of batteries. A final decision was made to select a more or less conventional nickel-cadmium battery, albeit with a new plate design, as proposed by a German firm. Another contender was from a US firm which proposed the use of an assembly of Nickel-Metal-Hydride cells for the main battery and a more conventional Nickel-Hydrogen stack for the auxiliary. As in the case of the solar cells, cost was an important factor in reaching this decision.

The Main Battery is composed of 20 cells of 40 A-hr capacity, for a 22-28 Vdc supply. These rectangular cells are from a terrestrial application, but have been very well characterized for space service. They are contained in three subassemblies, two of seven cells and one of six cells. The seven cell assembly is 11.5-kg mass and the respective assemblies will be mounted to reinforced Divider Panels, as previously discussed. The selection of the location of the lighter six cell subassembly will give us an option to use in achieving spacecraft balance.

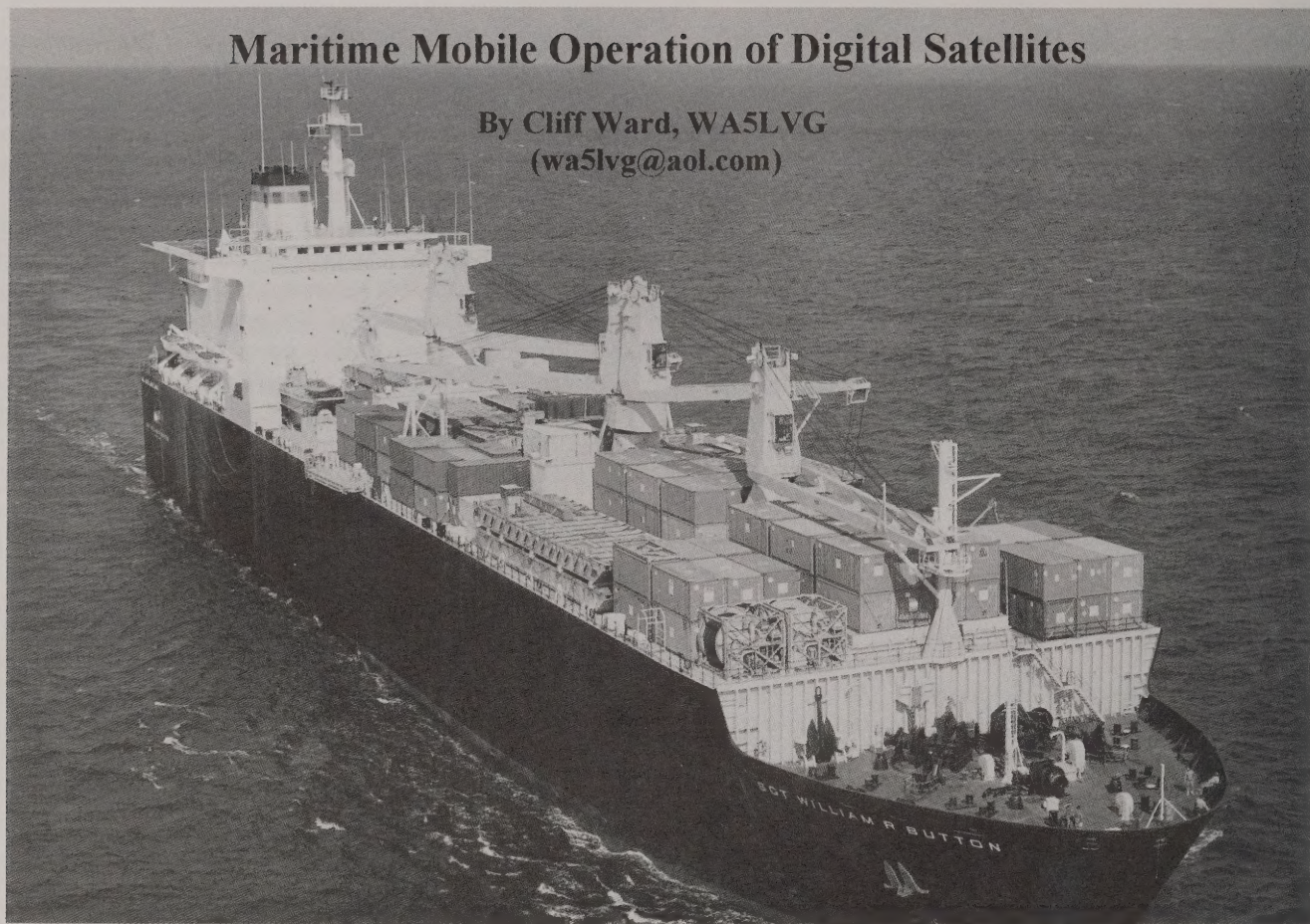
For the Auxiliary Battery, a relatively new 10 A-hr cylindrical cell has been selected. A total of 40 of these cells will be mounted in two 20-cell parallel strings. The entire group is divided into four, ten-cell subassemblies, mounted to the remaining three Divider Panels. As one panel will need to mount two of these subassemblies, we are again provided with a tool for spacecraft balancing.

Summary

Providing the *containment* for all of the systems and experiments for the Phase 3D spacecraft has provided an interesting engineering experience for quite a number of us on the team. We are confident that this effort will translate into a very long-lived mission for us to all enjoy in the communications afforded by Phase 3D. ■

Maritime Mobile Operation of Digital Satellites

By Cliff Ward, WA5LVG
(wa5lvg@aol.com)



The *MV Sgt. William R. Button* is a roll-on/roll-off and general cargo ship, that is stationed in the Pacific. The author experienced numerous challenges in establishing a digital satellite station on the aft section of the ship.

Since I live and work on a ship that is always on the other side of the globe from home, it is not often practical or possible to get a phone patch home via HF. Even getting into some Amateur Radio HF Pactor bulletin boards is tough and unreliable. There are of course commercial methods of calling home, but they are all expensive; for example Inmarsat calls are \$10 per minute. Amateur Radio Pacsats on the other hand are accessible from most of the earth's surface several times each day, and messages for the other side of the world can often be picked up within a few hours of posting.

When I got home from sea I put a query on a local 2 meter repeater, asking who works the digital birds. I was quickly referred to John Arnold, W5CUD (my Elmer). I found that John was very happy to assist me through the complexities of getting on the digital satellites. Two months later I returned to my ship with an FT736, PacComm TNC, Trakbox, mast mounted pre-amp, cables and connectors. I had the antennas shipped to where I met my ship.

Installation of radio equipment on a ship takes special considerations. Antennas must be well constructed and mounted, and connections have to be well sealed so that they will survive salty air and spray, constant winds (including those of super typhoons which may be in excess of 160 knots), and the ship's vibration. Installation of the equipment below decks often means it must either be bolted to the desk or, as in my case, strapped to the desk with stainless steel banding material. Murphy's Law for ships is that if something can possibly move – it will! Running cables on a ship is the real work. I knew that I could get by with a 100 meter spool of Aircom cable for the two runs. This was the shortest distance I could run and maintain proper cable isolation from other systems. I never seriously considered heliax since the nature of the cable runs would not be practical with such rigid material. Running the cables involved taking down overhead panels, pulling the cables within existing cable troughs, making six steel bulkhead (walls on ships) penetrations per cable, and involved the installation of kick-pipes for cable exits to the outside. I had the foresight to purchase some stainless steel 1"

pipe when home and brought 4-16" pieces with me in my luggage. The engineers drilled out the holes where I wanted them in the flying bridge deck by the mast and welded in the pipes. At the top of these pipes I threaded and inserted stuffing glands to seal against water entry.

I selected Hustler Spirit verticals for the antennas in order to meet the structural requirements and avoid the need to keep antennas oriented with respect to north as the ship moves. Hustler's 0 dB gain units maintain an excellent pattern to almost 40 degrees elevation. A low earth orbit satellite is below 40° for significant fractions of many passes, so these antennas will provide adequate periods for satellite operation. I mounted these antennas on top of the mast and both are free and clear at 176 feet off the water, an unbelievable view from up there! They are also over the pattern of the 2700 MHz radar so their is no interference either way.

Most of my operation is between two ports approximately 120 nautical miles apart. I have found that when we shift from one port to the other it's not necessary (with

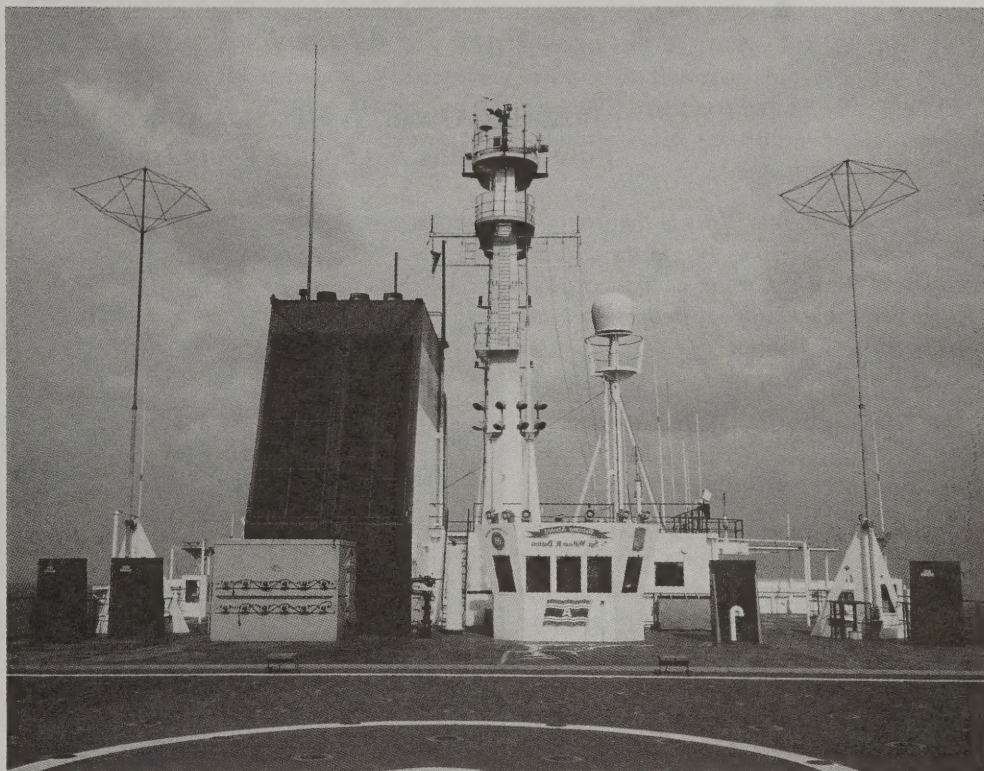
the 9600 birds) to enter a constant change of position in Wisp and my Trakbox, my 20 kHz filters are wide enough for what little error the incorrect position has. Mid-way between ports I change *positions* to the next port. However, underway to far away ports I change positions 3-5 times a day. The ship's speed is less than 16 knots. I update positions at 0800, 1200, and 1800. Before I go to bed I look at how the satellite passes are *grouped* during the night and generally enter positions in advance for the ship's proposed position. I've found that close (within 60 naut. mi.) seems to be close enough!

How well does it work? I get into the satellites quite well except when the footprint includes The Phillipines. There, 2-meter radios are used in taxi cabs and by various businesses, so there is tremendous 2-meter uplink QRM. Dave Chartier, W1YRM (my Guam Elmer) has difficulty getting into the birds, and he is using directional antennas. The satellite's receiver is just overwhelmed.

My footprint can cover from Northern Australia to Southern Japan. When the footprint is to the east (over the ocean) W1YRM and I may be the only stations in the queue. However, when it gets near Japan the queue fills in a picosecond. I find the Japanese Amateurs to be very orderly and professional and getting into the queue is easier than you may think, considering my antennas and the number of JA's on the birds. My best download so far is 980K! I look forward to my first 1Mb download.

Since we are 16 hours ahead of my home near Tyler, Texas, my day is their night. The bright part of my day is checking my messages each morning and downloading a message from home. W5CUD and Howard Collier, WB5EKW transfer my messages to/from home via Internet. Time certainly passes faster, and the world seem a little smaller, when you can keep a running dialog with the home front.

I would like to express my appreciation to W5CUD and W1YRM for all the patience and assistance they gave me in getting started, and to Chris Jackson, ZL2TPO for the wonderful Wisp software that makes it easy. Now to see if I can get Wisp running in a Wine Window under Linux! ■



Standing on the aft end of the helo deck and looking forward at the antenna array that surrounds the wheelhouse, mast, and stack. The helo deck is 100' and the top of the mast is 176' above the water. Visible are two 500 kHz antennas that are 40' in height. The dome is an INMARSAT antenna. (WA5LVG Photo)



Part of the mast antenna array on the MV Sgt. William R. Button, with Apra Harbor, Guam in the background. From left to right, 435 MHz vertical with SSB Electronics preamp, 400 MHz Transit satellite navigation antenna, wind anemometer, and 145 MHz vertical antenna. (WA5LVG Photo)

Mars Global Surveyor

Part 1 : Mars Relay Experiment

Michael R. Owen, W9IP, St. Lawrence University, NY
John L. Callas, NASA Jet Propulsion Laboratory, CA

Editor's Note: This is the first of a two part series on the Mars Global Surveyor. Part 2: Orbital Maneuvers and Radio Science will appear in the next issue of The AMSAT Journal.

Introduction

The Mars Global Surveyor (MGS) is scheduled for launch in November 1996, inaugurating a decade-long program of exploration of the Red Planet. With the program managed by Jet Propulsion Laboratory (JPL), NASA plans to launch two spacecraft to Mars every Earth-Mars alignment opportunity (approximately every two years). These missions will include a combination of orbiters and landers to explore Mars in a comprehensive and systematic way. Many orbiters will carry UHF radio relays to provide data communication between several Mars-landed systems and Earth.

Mars Global Surveyor will carry a radio relay system called the Mars Relay (MR, Figure 1). The Mars Relay will provide communication support between several Russian small lander stations on the surface of Mars and the orbiting Mars Global Surveyor. Future missions, planned for launch in 1998 and beyond, will also use the relay on MGS for surface data return.

In support of the Mars Global Surveyor Mission, JPL plans to perform a near-Earth test of the Mars Relay. Approximately 20 to 30 days after launch of MGS, JPL will initiate a test of the MR employing UHF communications equipment on the Earth. Because the MR operates at frequencies in the 70cm band, an opportunity exists for students and Radio Amateurs to participate in the near-Earth test of the Mars Relay. Using 70cm antennas, individuals will be able to listen for the Mars Relay beacon operating on 437.1 MHz at a distance of 6-8 million kilometers.

The Mission and Spacecraft

Mars Global Surveyor is the first step in a planned decade-long series of missions

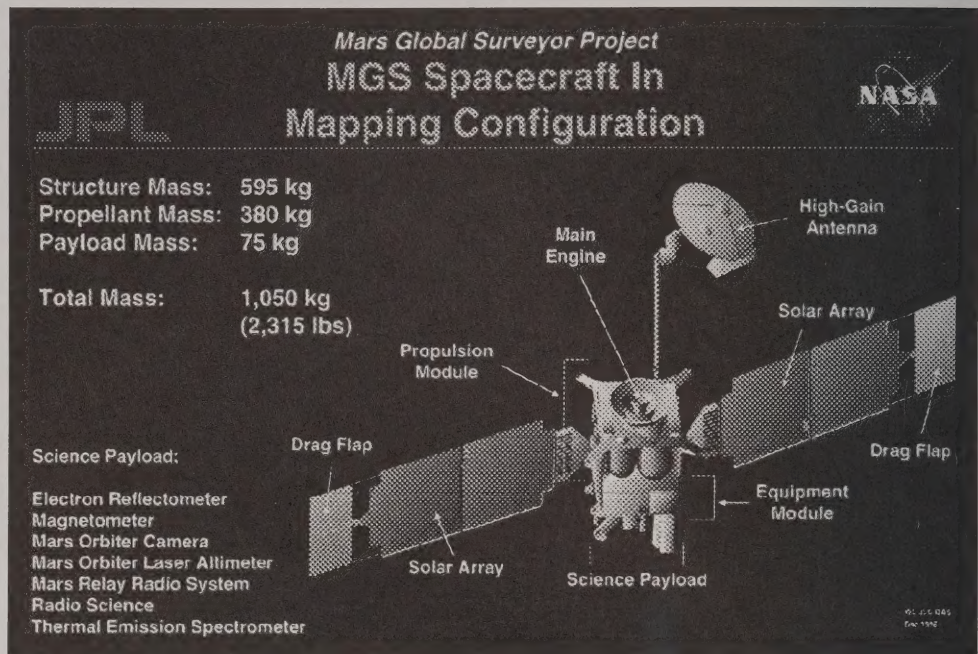


Figure 1.

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|-------|----------|----------|--------|----------|
| 328ft | \$252.56 | "N"-conn | \$8.95 | |
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to explore Mars. MGS will recover the majority of the science objectives originally planned for the ill-fated Mars Observer which lost contact with Earth in August, 1993. MGS, currently being built for JPL by Lockheed Martin in Denver, Colorado, carries six of the original eight Mars Observer instruments. These instruments are the Mars Orbiter Camera (MOC), the Mars Orbiter Laser Altimeter (MOLA), the Magnetometer/Electron Reflectometer (MAG/ER), the Thermal Emission Spectrometer (TES), the Radio Science/Ultra-Stable Oscillator (RS/USO), and the Mars Relay (MR).

Mars Global Surveyor will be launched to Mars in November 1996 on board a McDonnell Douglas Delta II 7925. The launch window for MGS extends from November 05 to November 25. MGS will then require approximately 10 months to travel 770 million kilometers of interplanetary space to reach Mars in September, 1997 (Figure 2). Upon arrival at Mars, the spacecraft will perform a Mars Orbit Insertion (MOI) propulsive maneuver to place the spacecraft in a highly elliptical capture orbit about Mars. Because of launch

vehicle limitations, the spacecraft cannot carry sufficient propellant to propulsively circularize the orbit into the final mapping orbit. Therefore, the spacecraft will exploit aerobraking in the Martian atmosphere to achieve the necessary change in velocity for entering a circular orbit (see Part 2). Approximately three months of aerobraking will be required to circularize the spacecraft's orbit to the point that small trim maneuvers can place the spacecraft in its final nearly-circular mapping orbit.

The mapping orbit will be a near-polar ($i = 92.9^\circ$) sun-synchronous orbit with an average altitude of 378 km above the surface of Mars (Figure 3). Sun-synchronicity will allow MGS to observe any region under the same lighting conditions each orbit, at approximately 2:00 PM local time on the day side of Mars and 2:00 AM local time on the night side of Mars.

The principal objective of the MGS is to photograph and map the surface of Mars. This will permit planetary geologists to study Mars in incredible detail. The MGS imaging system will permit wide-angle

views with a surface resolution of 280m per pixel, and narrow-angle views with resolution of only 1.4 m per pixel. (Compare this resolution with the NOAA satellite "high resolution" HRPT/AVHRR sensors whose resolution is approximately 1.4 km per pixel.) In addition, the laser altimeter aboard the Mars Global Surveyor will provide planet-wide topographic elevation surveys with $\pm 2\text{m}$ spot resolution ($\pm 30\text{m}$ globally).

From its low, circular mapping orbit, MGS will carry out the following science objectives at Mars:

- Characterize surface morphology at high spatial resolution to quantify surface characteristics and geological processes.
- Determine the composition, map the distribution, and measure the surface thermophysical properties of surface minerals, rocks, and ices.
- Determine globally the topography, geodetic figure, and gravitational field.
- Establish the nature of the planetary magnetic field and map the crustal remnant magnetic field.

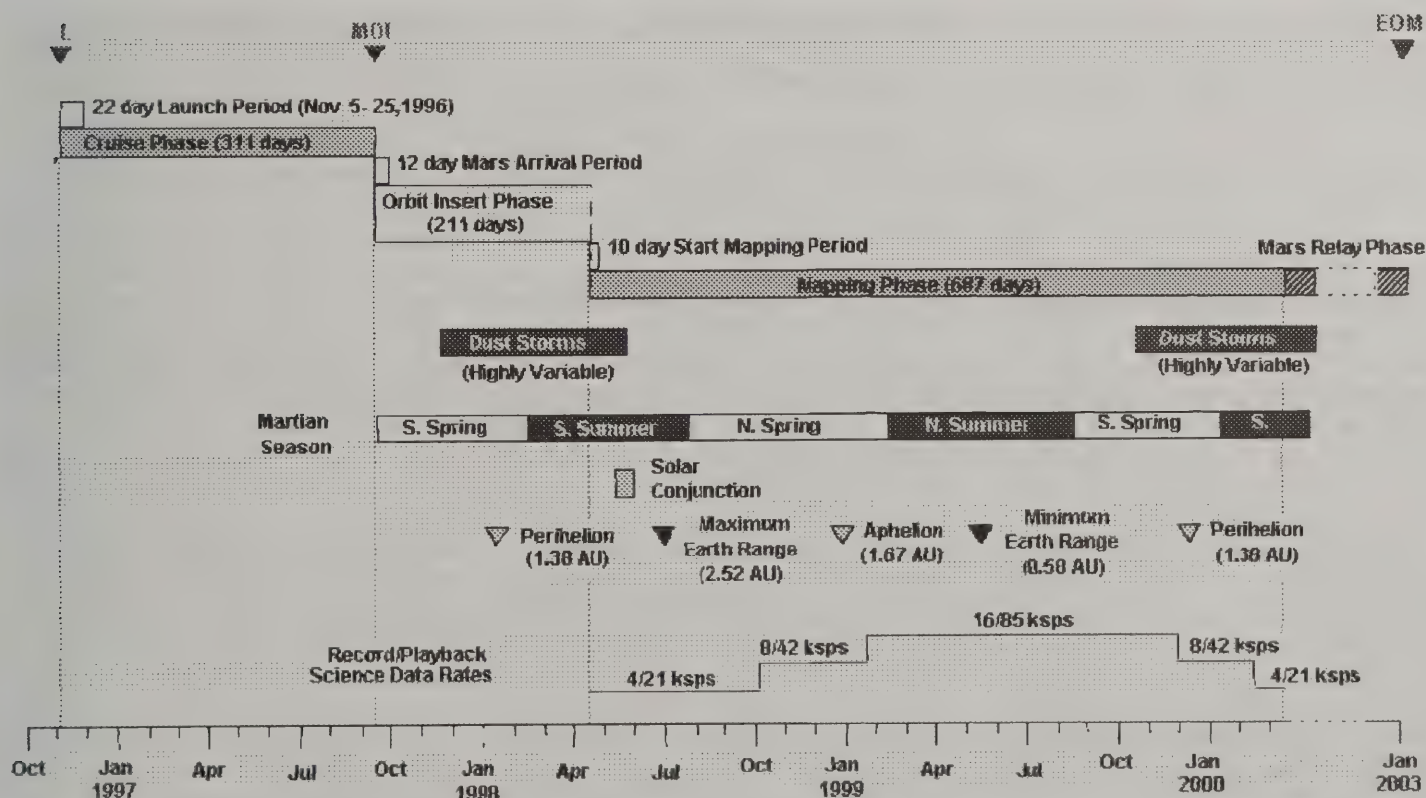


Figure 2 - Mars Global Surveyor Mission Calendar

- Monitor global weather and thermal structure of the Martian atmosphere.
- Study surface-atmosphere interaction by monitoring surface features, polar caps, polar thermal balance, atmospheric dust, and clouds over a seasonal cycle.
- Provide multiple years of on-orbit relay communications capability for Mars landers and atmospheric vehicles from any nation interested in participating in the International Mars Surveyor Program.
- Support planning for future Mars missions through data acquisitions with special emphasis on those measurements which could impact landing site selection.

The Mars Relay

Mars Global Surveyor will carry the MR supplied by the Centre Nationale d'Etudes Spatiales (CNES, the French Space Agency). The MR consists of a 6 kg electronics package and a 70-cm quadrifilar helix antenna. The antenna is designed for right-hand circular polarized (RHCP) transmission and reception with a peak antenna gain of approximately 2 dBi. The MR is capable of FM and CW beacon transmission at 1.3 watts on a single frequency of 437.1000 MHz, and phase modulated telemetry reception on two frequencies of 401.5275 MHz and 405.6250 MHz at two data rates of 8 and 128 kilosymbols per second. A total of 16 possible modes are available including two test modes for the MR.

The MR is intended to provide radio-relay support between unmanned Mars landers and Earth. Several small landers are under construction. They include the Mars Surveyor '98 and a series of international landers and surface penetrators from the Russian Mars '96 mission. Few of these Mars-surface devices will be capable of communicating directly to Earth. Instead, the orbiting Mars Relay (on board the Mars Global Surveyor spacecraft) will relay information between the landers and Earth, acting like an orbiting Martian repeater.

The MR beacon, to which Amateurs will try to listen, alerts Mars landers to the availability of the MR. In order to conserve landers' battery power, their transmitters must be activated only when the MR is within view. The landers will know that the MR is within view by listening for the MR's beacon on 437.100 MHz. The MR beacon signal is frequency modulated with

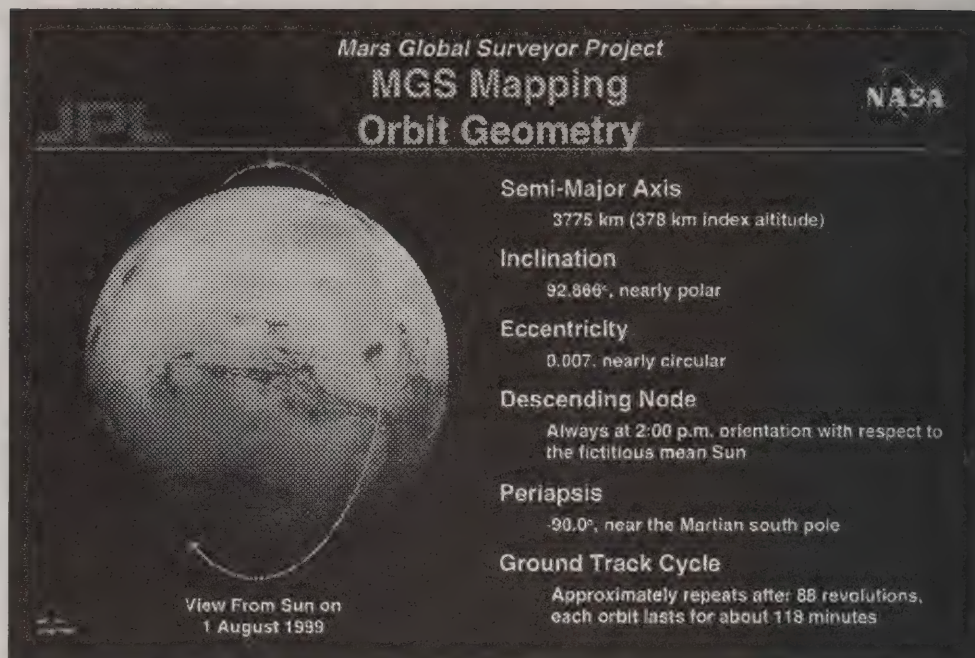


Figure 3

sub-carriers to initiate a handshaking protocol with the lander stations. When the link between the MR and the lander station is established, the MR is then able to receive the telemetry stream from the surface station. This protocol of link acquisition and telemetry reception is repeated every 16 seconds until all telemetry transmission is completed or the link is lost when the spacecraft moves from range.

The Near-Earth Experiment

A near-Earth test of the MR is planned in order to validate proper operation of the Mars Relay prior to arrival at Mars. Sometime between 20 and 30 days after launch, the spacecraft will be between 5.6 and 8.4 million km from Earth. At this time the spacecraft will be in its nominal cruise attitude of array normal spin (ANS) with the spacecraft spinning about its X-axis at a rate of 0.01 rpm. Because of the need to provide sufficient illumination to the solar arrays and the need to have the spacecraft's X-band low-gain antenna (LGA) pointed near Earth, the spacecraft spin axis is pointed 60° off the Sun towards the Earth. This attitude will result in the Earth-line passing through the peak gain (approx. 2 dBi) of the Mars Relay antenna once every 100 minutes. For approximately 40 minutes out of every 100 minutes, the MR antenna gain along the Earth-line will be greater than 0 dBi. A plot of the MR antenna gain along the Earth-line as a function of spacecraft rotation time is shown in Figure 4.

During the near-Earth experiment the Mars Relay will be powered up and initially set to the *beacon only* mode. This mode will transmit an unmodulated 1.3-watt carrier (CW) at 437.100 MHz. The MR will remain in this mode for at least 24 hours. This will permit Amateurs world wide to detect the signal and observe the fluctuation of the signal as the spacecraft rotates every 100 minutes. These measurements will be used to validate the far-field antenna pattern analysis that will have been performed on the MR prior to launch.

Following this period, the MR will be stepped through selected subcarrier modulated modes, each for a period of 100 minutes allowing ground receivers to observe one complete spacecraft rotation with each mode. The modulated signal will be much more difficult to detect than the CW signal. During these modulated modes, simulated lander transmissions may be attempted from the Earth. The simulated transmission will contain a pseudo-random number sequence radiated with a data rate of 8 kilosymbols per second. If successful, the MR will detect and lock on this simulated signal and demodulate the random number sequence. These data and other MR telemetry will then be returned to Earth via the spacecraft X-band downlink through the Deep Space Network (DSN). After completion of the subcarrier mode tests, the MR will be returned to the *beacon only* mode for an additional 24 hours. The near-Earth MR test will then be concluded.

The main challenge of the experiment will be to hear the MR beacon at all. Its low power and nearly omnidirectional antenna, coupled with its great distance from the Earth will mean that the beacon signal will be very weak and fluctuating due to spacecraft rotation. Additionally, Doppler effects from the Earth's rotation and relative spacecraft velocity will result in an ever-changing receive frequency. An antenna array with 21 dBi gain (equivalent to 4 long-boom crossed yagis) and a good receiving system (150 K equivalent noise temperature) will receive the beacon at a level of approximately -177 dBm. Stations with larger arrays and quieter preamplifiers will receive the beacon better, of course.

A signal strength of -177 dBm is too weak for normal "by-ear" detection for most stations so some form of digital signal processing (DSP) will be necessary. Programs to enhance detect extremely weak signals have been used by the EME (Moonbounce) community for several years. One of the most popular programs is FFTDSP by Mike Cook, AF9Y. This program uses a *SoundBlaster* digital audio card in a DOS computer to simulate very narrow bandwidths necessary for weak signal detection. It displays received signals on a multi-colored "waterfall" display. An effective bandwidth of about 0.3 Hz will be

necessary for a 21 dBi antenna and 150K receiver to detect the MR beacon with a 6 dB signal-to-noise ratio.

Uplink transmissions near 401 MHz to the Mars Global Surveyor/Mars Relay will be attempted by ground-based facilities. It appears likely that Amateurs, using one of the large parabolic dish antennas at Stanford or Goldstone, California, will be involved in this portion of the experiment as well. In addition, Amateurs using the Algonquin Space Complex 46m (150') and the Deep Space Exploration Society (Table Mt., Colorado) 18m (60') dishes may listen for the beacon.

NASA Needs Amateurs!

NASA's Deep Space Network of large radio antennas and sophisticated receivers is capable of extraordinary sensitivity. However, the DSN is suited best to operation above about 2 GHz (S-band and above). The 437.1 MHz Mars Global Surveyor beacon is too low in frequency for the DSN to monitor effectively. As a result, Amateur Radio assistance is critical to this portion of the in-flight spacecraft testing. Furthermore, NASA and JPL seek to more fully involve Amateurs and the public at large in space activities. The Mars Global Surveyor Mars Relay experiment is an

excellent opportunity for amateurs to show their willingness and capability to cooperate with NASA in supporting the exploration of space.

How Can I Participate?

This article is a follow-up to a preliminary announcement of the experiment in *QST* for January, 1996 (p. 44-45). Further information will be published in *QST* and in *The AMSAT Journal*. If you have access to the Internet, details of the MR experiment will be contained on the Mars Global Surveyor Home Page located at <http://mgs-www.jpl.nasa.gov>. An Internet e-mail reflector named Mars-Net has been established at St. Lawrence University. To subscribe, address a message to: Listserv@VM.STLAWU.EDU. The message should say SUBSCRIBE Mars-Net followed by your name and callsign. For example, if one of the authors wanted to subscribe, their message would say *SUBSCRIBE Mars-Net Michael Owen W9IP*. You will receive e-mail confirmation of your subscription. Finally, you should now begin to plan your antennas and receiving systems, learn about DSP, and acquire tracking software for pointing your antennas. ■

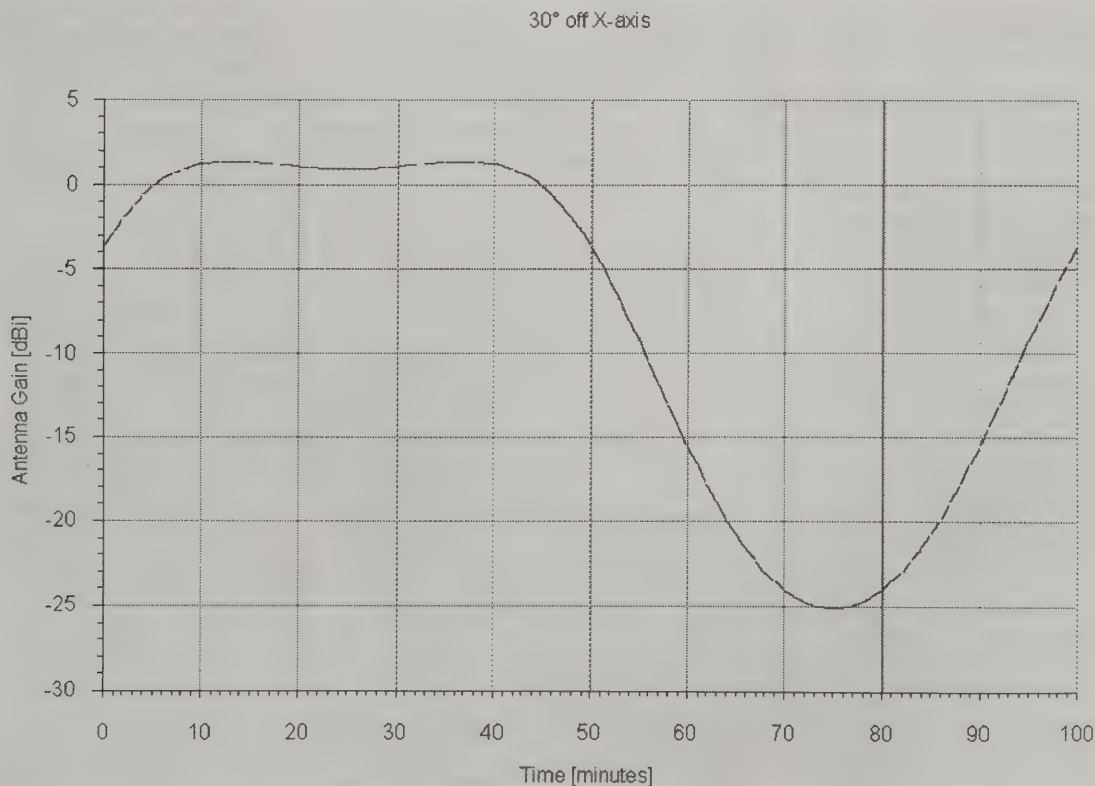


Figure 4. Mars Relay Antenna Gain Along the Earth Line

Keplerian Element Estimation for Radio Sputnik 15

Ken Ernandes, N2WWD (n2wwd@amsat.org)

Editor's Note: The following article was originally presented last October at the AMSAT-NA 13th Space Symposium and Annual Meeting. Ken will present a similar article on a Keplerian element estimation for Phase 3D in the next issue of The AMSAT Journal.

Introduction

The pre-launch estimation of Keplerian elements for Radio Sputnik 15 (RS-15) was the first live test of a modeling technique that provides interim elements for new Amateur Radio satellites. While the technique was found to generate useful Keplerian elements, its success was overshadowed by an unexpected sequence of events that resulted in a long delay in the availability of the official elements. Therefore the estimation process continued for several weeks, refining the Keplerian elements in order to accommodate Amateur Radio operators during the period in which the official elements were not available.

Pre-Launch Estimation

This section provides an overview of the pre-launch modeling process and element estimation. Mathematical details are omitted in favor of conceptual illustrations.

The flight to orbit was modeled based on the pre-launch orbital parameters and the launch site information provided by Russian amateurs. This information was not sufficient to define the intermediate orbit(s) and sequence of events (that is the mission profile) necessary for RS-15 to achieve its final orbit. Therefore, part of the orbital estimation process was to use reasonable values for the unknown parameters and to presume the simplest possible mission profile for the satellite to achieve its intended orbit.

Russian amateurs provided unofficial information for RS-15 that indicated a circular orbit 2300 km in altitude with a 67 degree orbital inclination. An altitude of 2300 km is too high for an efficient direct orbital injection with contemporary booster technology. The simplest [reasonable] mission profile to achieve such an orbit is

for the booster to inject the satellite (and the attached upper stage) into an elliptical transfer orbit (Figure 1). The upper stage and attached satellite then coast in unpowered flight to apogee (the highest altitude) of the transfer orbit. The apogee of the transfer orbit was targeted to be equal to the final orbital altitude (in this case 2300 km). The perigee (the lowest altitude) of the transfer orbit must be within a reasonable injection altitude for the launch booster. For both simplicity and efficiency, injection at perigee was presumed.

To achieve the final orbit, the upper stage re-fires at apogee of the transfer orbit increasing the spacecraft's speed. The thrust cutoff is selected so that the velocity increase establishes a circular orbit at the apogee altitude.

A few days before the launch, a new bulletin was posted by UA3CR of AMSAT-Russia with revised information for RS-15. The orbit was revised from circular to elliptical with altitudes of 1946 km for apogee and 1809 km for perigee. The inclination was also adjusted to 64.2 degrees. The planned launch date/time was listed as 26-Dec-94 / 03:00 UTC.

The switch from a circular to an

elliptical final orbit required yet another assumption to be made: the orientation of the apsidal (apogee-perigee) line. The most likely scenario was for the perigee of the final orbit to be the apogee of the transfer orbit (Figure 2). This assumption did not require any major adjustment to the basic mission profile; the transfer orbit's apogee altitude and its post-burn velocity just needed to be adjusted to establish the final orbit's apogee and perigee altitudes.

The mission profile begins with the powered flight of the booster (the ascent profile) originating at the launch site (Baikonur for RS-15). The ascent profile of the *Rokot* booster (composed of an SS-19 ballistic missile and a *Briz* 3rd stage) was unknown. In the absence of specifications for the booster, a high fidelity simulation could not be performed. Therefore, a typical profile was presumed in which: 1) the time from launch to transfer orbit injection, 2) the injection altitude, and 3) the downrange Earth-central angle (along the great circle) were selected as: 6 minutes, 150 km, and 6 degrees respectively (Figure 3).

The ascent profile was projected into the inertial azimuth plane required to establish the 64.2 degree inclination from the Baikonur launch site within the range

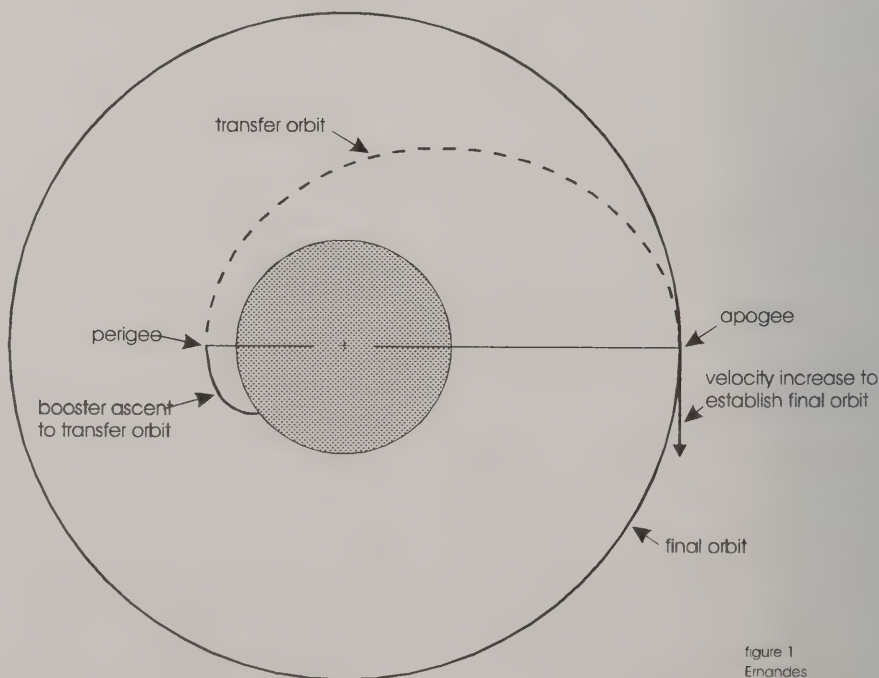


Figure 1. Presumed RS-15 Mission Profile for a Circular Orbit

safety constraints (a northerly azimuth). The transfer orbit injection occurs at booster cutoff (at the end of the ascent profile). Note that some error was introduced by modeling an inertial boost plane. While the induced error is probably small when compared with other the errors, plans are to correct for the Coriolis (Earth rotational) effects during boost in future applications.

The end of the booster ascent profile is the time and the position of the transfer orbit injection. The injection velocity is computed using basic orbital mechanics equations. The velocity is computed to achieve the desired apogee, which occurs one half a revolution after transfer orbit injection. Since injection is modeled at perigee, there is no radial component of velocity. Therefore, velocity is directed horizontally in the azimuth plane.

The transfer orbit is determined by the injection time and the injection position and velocity vectors. A set of Keplerian elements is computed by entering these parameters into the Vector to Two-Line Elements (VEC2TLE) software. The first apogee of the transfer orbit is the time and position of final orbit insertion (as indicated by Figures 1 and 2). An impulsive thruster firing maneuver is modeled at transfer orbit apogee to establish the final orbit with the specified apogee and perigee altitudes. The time and the position and velocity vectors of the final orbit insertion are then entered into VEC2TLE to compute the corresponding Keplerian elements for the final orbit.

Even though the scheduled launch time was provided for RS-15, launches do not always occur on the scheduled date or at the scheduled time. A change in launch time results in a change to the Keplerian elements. To accommodate launch time flexibility, the orbital injection times were referenced to Mission Elapsed Time (MET) and the vectors were generated in the Earth-Fixed Greenwich (EFG) [a.k.a. True of Day Rotating (TDR)] reference frame. The EFG reference frame rotates with the Earth. Therefore, position and velocity vectors in this reference frame remain the same, regardless of launch date or time.

The rationale for choosing the time-independent EFG reference frame was to make the position and velocity vectors useful to the Amateur Radio satellite

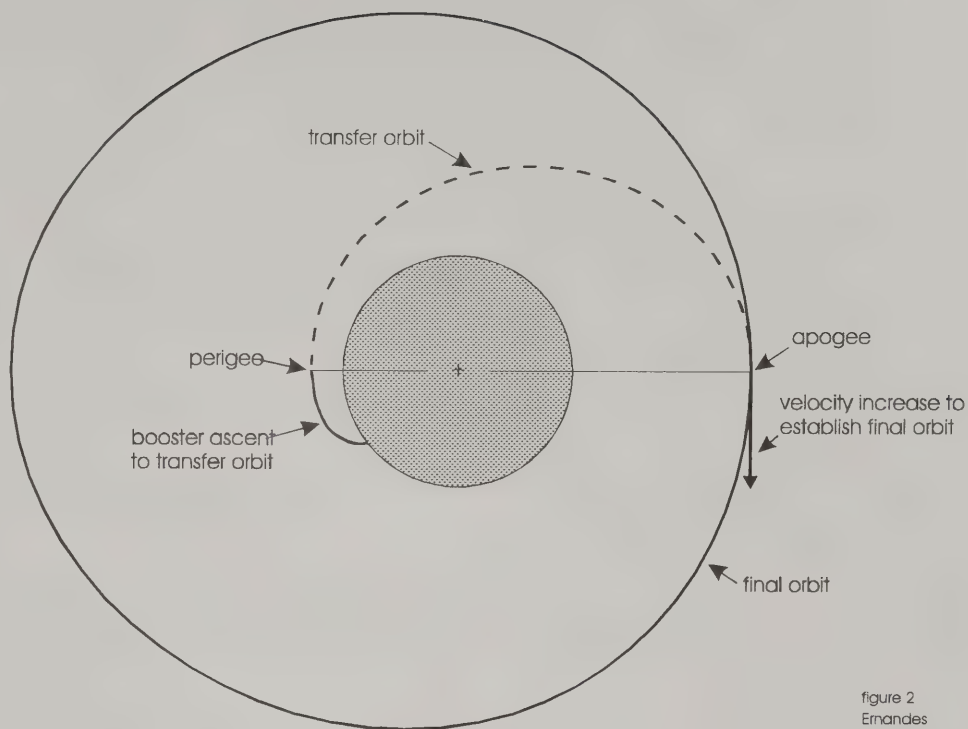


Figure 2., Presumed RS-15 Mission Profile for an Elliptical Orbit

operator. The MET-referenced EFG state vector was released along with the Keplerian elements (corresponding to the planned launch time). Providing the EFG state vector allowed the user to enter any updated launch date and time into VEC2TLE and immediately compute the corresponding [updated] Keplerian elements.

The time-independent MET/EFG state vector estimated for RS-15's final orbit were:

```
Vector format = 10107
Satellite Name: RS-15
Catalog Number: 99915
Epoch MET: 0.03931712963
              0/00:56:37.000 MET
EFG E: -3623.178002 km
F: -4408.622502 km
G: -5870.758751 km
Edot: 5.550164511 km/s
Fdot: 0.518089209 km/s
Gdot: -3.814378116 km/s
ndot/2 (drag): 0.00000000682 rev/day^2
nddt/6: 0.00000E+00 rev/day
^3 Bstar: 1.40330E-05 1/Earth Radii
Elset #: 2
Rev @ Epoch: 1.64664923167
```

The corresponding Keplerian elements based on the nominal launch date / time of 26-Dec-94 / 03:00 UTC are:

```
Satellite: RS-15
Catalog number: 99915
Epoch time: 94360.16431713
Element set: 2
Inclination: 64.2029 deg
RA of node: 174.3271 deg
Eccentricity: 0.0093331
Arg of perigee: 234.2744 deg
Mean anomaly: 358.4925 deg
Mean motion: 11.56772041 rev/day
Decay rate: 6.82000E-09 rev/day^2
Epoch rev: 1
```

Feedback and Correction

It should be clear by now that a lot of approximation and *educated guessing* was used for the pre-launch estimation of the Keplerian elements. In the absence of more definitive information, it would be too optimistic to expect these elements to predict the position and motion of RS-15 perfectly from the onset. What is very realistic, however, is to expect the estimated elements to provide good *ballpark* predictions of pass times. Once a series of observations is made and compared with the predictions of the estimated elements, a

trend analysis can be performed which can indicate where to make logical adjustments to the mission profile and/or estimated state vectors. These adjustments are then translated into new Keplerian elements.

The first orbital *feedback* that I received for RS-15 was from Andy Thomas, G0SFJ who posted a message on the Internet AMSAT-BB with the times he observed the satellite's beacon. G0SFJ's first observations, made well within the first day after launch, indicated that RS-15 was lagging approximately seven (7) minutes behind the pre-launch elliptical (1946 x 1809 km) Keplerian elements estimate. With no additional information, I presumed the apogee and perigee altitudes to be correct and computed a new set of Keplerian elements with a 7 minute launch delay. This was accomplished with the above pre-launch MET/EFG state vector, by re-setting the launch date/time in VEC2TLE to 26-Dec-94 / 03:07 UTC.

Observations of subsequent RS-15 passes revealed a drift of the AOS/LOS times when compared with the predictions made by the latest Keplerian elements. The recorded differences in the observed AOS/LOS times showed RS-15 getting progressively later than predicted on each pass. This very linear trend indicated that RS-15 was in a higher altitude orbit than that dictated by the pre-launch 1946 x 1809 km apogee and perigee information. The measured difference in orbital period translated directly into an adjustment in mean orbital altitude. Since there was no indication of where the orbital altitude increase should be applied (apogee, perigee, or both), an interim circular orbit was estimated based on the measured orbital period.

Predictions from the interim [circular] Keplerian elements turned out to be lagging RS-15's actual AOS/LOS times by a few minutes. These observations were independently confirmed by Jim Mollican, N2NRD and John Gordon, KD2JF.

On 27-Dec-94, a RS-15 launch report was issued by Leo Maksakov, RA3AT relaying post-launch information from the RS-Group (RS3A). The report confirmed the launch time of RS-15 on 26-Dec-94 / 03:00 UTC. The apogee and perigee altitudes were listed as 2165 km and 1885 km respectively. The inclination was also

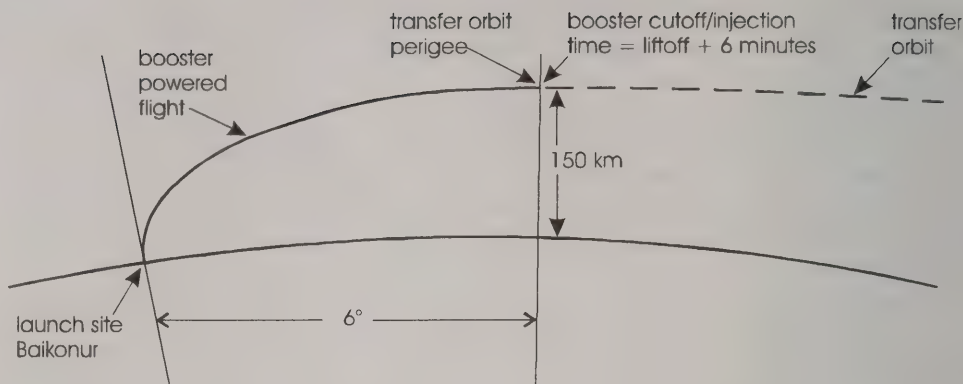


figure 3
Ernandes

Figure 3. Presumed Ascent Profile for Rokot Booster

slightly different from the pre-launch information, now at 64.59 degrees.

The RS-15 launch report provided a far more complete picture than was previously available. Still missing were the details of the booster ascent profile and the transfer orbit. The result was that there was still some uncertainty in the final orbit injection time and location, which in turn resulted in some ambiguity as to the orientation of the line of apsides (apogee-perigee line) within the orbital plane. The original presumptions were used to fill in the missing information. Based on the updated information, the following set of updated Keplerian elements was generated:

Satellite: RS-15
Catalog number: 99915
Epoch time: 94360.16459491
Element set: 3
Inclination: 64.5927 deg
RA of node: 174.9040 deg
Eccentricity: 0.0173416
Arg of perigee: 233.4418 deg
Mean anomaly: 0.0000 deg
Mean motion: 11.27220920 rev/day
Decay rate: 4.74000e-09 rev/day^2
Epoch rev: 1

Because of the missing information, I sent a message to RA3AT (at rsgroup@olymp.msk.su) requesting additional orbital information in whatever form he might be able to provide. His response (about a week later) was that they, unfortunately, have a very difficult time obtaining official orbital information. In fact, the orbital information they were using was coming from NASA Bulletins, Internet, and Packet Radio. In response, I

provided RA3AT with my estimated elements for RS-15.

Several days after launch, Keplerian elements for RS-15 began appearing on the OIG RAID RBBS release point at NASA Goddard Space Flight Center (GSFC). The elements appearing for satellite #23439 were a very close match to my estimated elements (set #3). At this point, I believed I was finished with the RS-15 orbital estimation process.

Within a day of the NASA/GSFC release of Keplerian elements for satellite #23439, the orbital periods of the subsequently-released element sets began to increase. Dennis Dinga, N6DD noted that the new elements represented much too high an orbit because their predictions were lagging well behind the observed passes of RS-15. Since the orbit for satellite #23439 did appear to originate from the RS-15 launch, I searched the GSFC OIG RAID RBBS database and found satellite #23440 to be a much better match to above element set #3. However, actual tracking of RS-15 indicated slightly late AOS/LOS predictions for these elements and they were drifting progressively later on each successive pass.

The inability of the Keplerian elements for either satellite #23439 or #23440 to accurately predict the pass times for RS-15 indicated that neither represented the orbit of this satellite. Since it was apparent that both objects originated from the RS-15 launch, the orbits of satellites #23439 and #23440 were traced back to their Point of

Closest Approach (PCA) with respect to each other. The Time of Closest Approach (TCA) for these two objects was computed at approximately 3.5 hours after launch; a few degrees after perigee for both orbits. The computed PCA conjunction information is listed below:

Relative Minimum Geometry
26-Dec-94 / 06:30:49.023 UTC
Primary: 23439 2) Secondary: 23440

Geo:	Lat (deg)	Lon (deg)	Ht (km)
(1)	-43.2488	316.3269	1883.9718
(2)	-43.2448	316.3271	1884.1723

ECI:	X (km)	Y (km)	Z (km)
(1)	-5148.6200	3147.6412	-5638.5125
(2)	-5149.0919	3147.9066	-5638.2318

Delta-V:	intrack (m/s)	crosstrack(m/s)	radial(m/s)
(1 v 2)	15.68	-6.09	-27.34

View:	azimuth (deg)	elevation (deg)	range (km)
(1 v 2)	33.6295	19.5063	0.6099

Because satellites #23439 and #23440 converged well to a PCA very close to their perigees, it was concluded that the two satellites were indeed pieces from the RS-15 launch. Since the pre-launch information provided in the December 1994 edition of *QST* made reference to a *parent satellite*, it seemed logical that satellite #23439 was probably that primary payload and that satellite #23440 was the upper stage *Briz* rocket body from the Rokot booster. The PCA of the two orbits,

occurring at 26-Dec-94 / 06:30:49 UTC, would then correspond to the deployment of satellite #23439 from the upper stage. If true, this would represent a bad assumption in the presumed mission profile, since deployment would have occurred at the second apogee of the transfer orbit.

The most disturbing aspect of the PCA information was the relative velocity (Delta-V) between the two objects. The total delta-V magnitude (approximately 32 meters per second) is very large. Moreover, deployments are generally made with delta-V in the intrack direction; the delta-V computed for the above PCA is directed rather randomly. This suggested that an anomalous situation occurred at or near the presumed deployment point.

A very encouraging fact about the PCA, however, was that its 1884 km altitude corresponded nearly exactly with the 1885 km perigee altitude provided by RA3AT for RS-15. With the altitudes aligning so conveniently, it seemed logical to presume that the separation of RS-15 from the upper stage occurred at or near the PCA and TCA of satellites #23439 and #23440. Since #23440 was presumed to be the rocket body, its position vector at the TCA was used as the presumed deployment position of RS-15. The velocity vector was computed (as described earlier) to establish the 2165 km apogee at the opposite side of

the orbit from the deployment position. The only change made was that the velocity vector was projected in the same (64.83 degree inclination) orbital plane as satellites #23439 and #23440, rather than the 64.59 degree inclination provided by RA3AT.

The orbital estimation algorithm was also enhanced, modeling the Earth's surface using the World Geodetic Survey of 1984 (WGS-84) ellipsoid. This was done to compute Earth-centered radii corresponding to the given apogee and perigee altitudes. The resulting Keplerian elements were:

Satellite: RS-15
Catalog number: 99915
Epoch time: 94360.27140046
Element set: 4
Inclination: 64.8314 deg
RA of node: 174.6168 deg
Eccentricity: 0.0175780
Arg of perigee: 310.1310 deg
Mean anomaly: 0.9271 deg
Mean motion: 11.27503470 rev/day
Decay rate: 4.77000e-09 rev/day^2
Epoch rev: 2

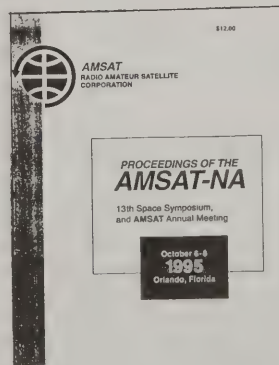
Three observations were made after tracking RS-15 for several days using estimated element set #4: 1) the apogee and perigee altitudes provided by RA3AT were an excellent match to the orbit of the presumed upper stage (satellite #23440), but did not exactly match the observed

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orbital period of RS-15; 2) the estimated elements for RS-15 had perigee occurring approximately 20 degrees forward of (later than) perigee for satellites #23439 and #23440; and 3) software Doppler shift compensation (based on the estimated elements) had a tuning bias in one direction for the first *half* of the pass that changed to a different tuning bias for the second *half* of the pass.

These observations indicated that the estimated elements for RS-15 were still not quite correct. Since the AOS/LOS times were reasonably accurate, the conclusion was that the error was primarily with the line of apsides. This could be manifested by an error in the orientation of the apogee/perigee line (consistent with observation #2) and/or errors in the actual apogee/perigee altitudes (consistent with observation #1).

Because of the close match in perigee altitude between satellites #23439 and #23440, this was retained as RS-15's estimated perigee altitude. Adjustments were made to the estimated apogee altitude in order to fine tune the orbital period to the actual pass times of the satellite. The actual perigee time of satellite #23440 was 26-Dec-94 / 06:23:52 UTC, approximately 7 minutes before the conjunction between it and satellite #23439. A new set of Keplerian elements was estimated from this adjusted deployment time and position:

Satellite: RS-15
Catalog number: 99915
Epoch time: 94360.26657407
Element set: 5
Inclination: 64.8377 deg
RA of node: 174.6064 deg
Eccentricity: 0.0181234
Arg of perigee: 290.3947 deg
Mean anomaly: 0.3861 deg
Mean motion: 11.27538755 rev/day
Decay rate: 4.77000e-09 rev/day²

Coordination With Space Command

It was clear from the beginning that the lack of: 1) precise tracking data, and 2) least-squares differential correction software, that the estimated Keplerian elements for RS-15 could not indefinitely predict the satellite's position and motion. Hence the heavy reliance of the amateur satellite community on the Space Command Keplerian elements released by NASA GSFC.

I discussed the matter of the unavailability of official Keplerian elements with Keith Baker, KB1SF, the AMSAT-NA Executive Vice President. Agreeing with his recommendation, I contacted Mr. Ron Roehrich, the Deputy Director for Space Analysis at United States Space Command (USSPACECOM). While not specific as to the nature of the difficulty with the RS-15 launch, Ron gave indications that there were multiple significant pieces on orbit with RS-15 and its upper stage. Since USSPACECOM's primary sensors usually only provide radar tracking data, it can be difficult to distinguish one payload from another or from another piece such as a rocket body.

I provided Ron Roehrich with my estimated element sets #4 and #5 so that the Space Command Orbital Analysts could compare them with the pieces they were tracking, and thus identify RS-15. After Space Command compared my elements with the pieces they were tracking, Ron telephoned me and indicated that the N2WWD-derived elements matched a piece they had tentatively identified as the *rocket body*. I explained to him that our only tracking capability was the active beacons and transponders on the *payload* (RS-15) and that we were blind to all other pieces. He accepted this as very encouraging news and indicated that we should expect an answer within the next few days. Shortly after coordinating with Ron, the official RS-15 elements released at NASA GSFC OIG RAID RBBS began matching both the estimated elements and the AOS/LOS pass times for RS-15.

In the meantime, Walt Daniel, KE3HP posted a message on the Internet AMSAT-BB regarding RS-15. Quoting an article from the 16 January 1995 edition of *Aviation Week and Space Technology*, Walt announced that RS-15's upper stage rocket body exploded approximately 3.5 hours after liftoff. The explosion scattered a debris cloud in orbit around RS-15. Clearly, the PCA computed between the Keplerian elements for satellites #23439 and #23440 (3.5 hours after launch) was actually the computation of the time and location of the upper stage explosion.

The *Aviation Week and Space Technology* article provided the most reasonable explanation for the mis-identification of RS-15. As mentioned earlier, Space Command's primary sensors

are radars that echo their signal off the satellites they are tracking. In routine operations, it's somewhat difficult to distinguish an active payload (such as RS-15) from a rocket body or other piece of debris. Thus while Space Command had precise orbits determined for RS-15 and the pieces in the debris cloud, the piece identification was only tentative.

Since Amateur Radio satellite operators only track active signals (satellite beacons and transponders), we were *blind* to the ambiguity or confusion caused by the debris cloud. Therefore, identification of RS-15 by these active signals was trivial using Amateur Radio equipment.

Coordinating RS-15 orbital data with Space Command was a significant milestone. Space Command used the N2WWD-derived Keplerian elements as an inexpensive, but complementary resource in the piece identification process. The Amateur Radio *estimated elements* were compared by Space Command against the orbits of the pieces they were tracking. This helped them in identifying RS-15 from the other pieces. Since this process brought about a flow of regular updates to RS-15's Keplerian elements, Amateur Radio satellite operators ultimately received the greatest benefit.

Conclusions

The estimation of Keplerian elements for RS-15 served not only to provide interim Keplerian elements for Amateur Radio satellite operators, but it also provided Space Command a convenient means of discriminating the RS-15 satellite from the upper stage debris cloud. This cooperative exchange provided positive identification of RS-15, which in turn initiated updates of high quality Space Command Keplerian elements.

The modeling technique used for RS-15 orbit estimation was an extension of the process that provides time-independent pre-launch orbital information to the amateur satellite operator. The successful use of this process for RS-15 orbit determination means that this type of pre-launch orbital data will be made available for future Amateur Radio satellite launches. Future directions, including improvements to this process, will depend on feedback and initiative from the amateur satellite community. ■

Shuttle Amateur Radio Experiment Status 1995

Frank Bauer, KA3HDO, AMSAT V.P. for Manned Space Programs
Matt Bordelon, KC5BTL, SAREX Principal Investigator

Abstract

The Shuttle Amateur Radio Experiment (SAREX) is sponsored by the American Radio Relay League (ARRL), the Radio Amateur Satellite Corporation (AMSAT) and the National Aeronautics and Space Administration (NASA). In 1995 SAREX has maintained its outstanding, multifaceted program of education, experimentation and Amateur Radio communication between astronauts on the Space Shuttle and ham radio operators and students on the ground. The SAREX Working Group and its hundreds of volunteers have worked hard to develop a robust, comprehensive SAREX program. Despite several challenges which have threatened the program in the past, this team has developed a well rounded, fully operational program on the Shuttle and are working with the NASA engineers, managers and astronauts in an effort to develop a permanent capability on the International Space Station. While not a guarantee, the SAREX team is *cautiously optimistic* that a permanent Amateur Radio station on the International Space Station will become a reality.

The SAREX team has successfully completed four Shuttle missions in 1995. Five more are being planned for 1996, including the potential for some long duration SAREX activities. The following represents some detailed highlights from 1995, some of the changes in the program and our visions for the future.

Introduction

The year 1995 will most likely be noted as a year of transition for the SAREX program. Over the past 11 years, SAREX has flown 19 times as a secondary payload on all 5 U.S. Space Shuttles. Tables 1 and 2 depict all the SAREX flights flown to date. NASA is currently shifting its manned space activity from short duration missions on U.S. Space Shuttles to long duration continuous

presence experimentation on the International Space Station (ISS). As NASA transitions, SAREX is striving to stay in lock-step with NASA's manned space plans. Through these efforts and international coordination with amateur space activities in other countries, the SAREX team hopes to provide a permanent Amateur Radio presence on human-tended space vehicles.

As was stated in Reference 1, the SAREX program has evolved through two major phases in its development cycle (Figure 1). The first phase, the pure experimental phase, introduced new Amateur Radio hardware and techniques to the Space Shuttle program and accomplished several firsts in manned space history. These include the first communications between astronauts and people on the ground outside of the *official* channels (usually reserved for presidents and heads of state). This occurred on STS-9. Other firsts included the first uplink and downlink of pictures on STS-51F, the first packet computer-to-computer radio link on STS-35 and the first video uplink on STS-37.

SAREX Phase II, which started in 1992, represents the operational frequent-flyer phase. During this phase of SAREX, the paperwork, tools and operational techniques have been honed to allow SAREX to fly up to 4-5 times a year on the Space Shuttle. This could only be accomplished through careful development of several specific SAREX configurations which allowed the generation of generic SAREX paperwork to meet Shuttle payload integration requirements. The Crew Training Plan was formalized and made more efficient; generic lessons were developed that could be used for every flight. In addition, a concerted effort was initiated to license the Space Shuttle astronauts. To date, almost half of the U.S. astronauts currently have Amateur Radio licenses. ARRL developed SAREX educational materials to be distributed to the schools. To support SAREX Phase II, AMSAT set up a network of volunteers who prepare the schools for their SAREX contacts. These volunteers, who comprise the AMSAT SAREX Operations

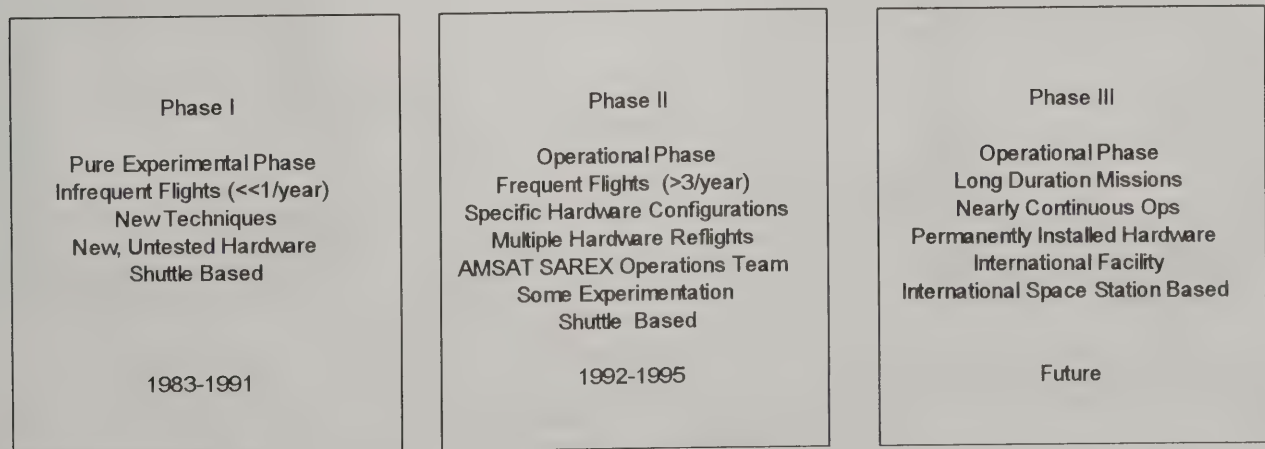


Figure 1. SAREX Developmental Phases

Team, provide real-time information bulletins to hams around the world and provide critical mission control support to the SAREX team at the Johnson Space Center.

The beginning of SAREX Phase III is represented by the current transition from short duration, intense, Space Shuttle flights to long duration U.S. presence on the Russian Space Station MIR and finally permanently-tended human operations on the ISS. As was required when SAREX transitioned from Phase I to SAREX Phase II, the SAREX team will need to evolve its hardware development, documentation and operations techniques to better serve the long duration activities in space during the Phase III era. Since both MIR and ISS represent international facilities, a much closer relationship with our international Amateur Radio partners is required. School-group contact, personal contact and experimental contact scheduling and preparation will also require new techniques and procedures. New hardware and new operating bands will naturally occur with a new facility. While this permanent Amateur Radio station will provide some new challenges to the SAREX team, it also promises to open the doors to some very exciting, new capabilities which will significantly enhance the SAREX educational outreach program. In addition, it will also provide hams on the ground more frequent, comprehensive access to space.

SAREX Working Group Changes

The SAREX Working Group consists of a core group of *board of directors* that manage the day-to-day SAREX activities and provide guidance and direction to the program. Figure 2 depicts the SAREX Working Group organization. The group consists of members from the ARRL, AMSAT and the Johnson Space Center Amateur Radio Club with Roy Neal, K6DUE, as the working group lead.

As shown in Figure 2, the new SAREX Principal Investigator is Matt Bordelon, KC5BTL. Matt has stepped in to assume the responsibilities of Lou McFadin, W5DID, who retired from the Johnson Space Center this past spring. Lou is a charter member of the SAREX team. His untiring support as the Principal Investigator of SAREX included the oversight in the development and integration of all SAREX hardware and oversight of SAREX operations at the Johnson Space Center. Matt has assumed these roles as well as supports our recent endeavor to incorporate SAREX on the ISS.

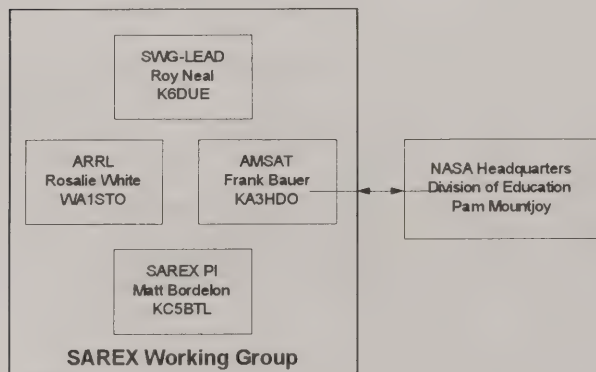


Figure 2. SAREX Working Group Organization

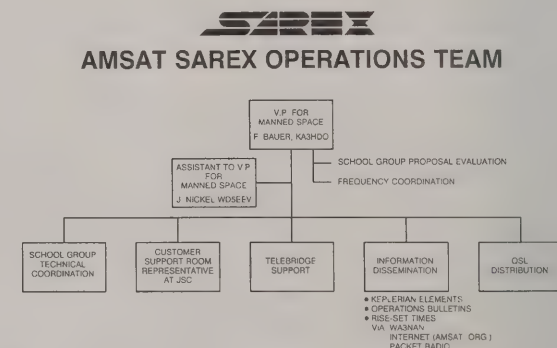
Guidelines

In 1993 the SAREX working group initiated the development of a set of written guidelines. This document has provided a written backbone to help the SAREX team develop a more comprehensive program. These guidelines have been reviewed and approved by the SAREX team, the Shuttle Program Office and the Astronaut Office. They define the mission planning requirements, particularly the deadlines for SAREX contact inputs to and from the mission timeliners and they aid in the selection of school groups. They define school group selection deadlines, requirements for school group applications, and also define specifics such as the number of contacts per mission and the number of SAREX missions per year. The most recent version of the guidelines is documented in Appendix A. These guidelines have resulted in solidifying SAREX as a frequent flyer payload on the Shuttle. Since our requirements are defined explicitly in this document, they have strengthened our relationship with the NASA team at the Johnson Space Center. As a result, we have significantly improved our chances to become a permanent payload on the ISS.

AMSAT SAREX Operations Team

AMSAT's primary role in the SAREX program is to provide technical support to the team and to foster interest in amateur space activities. In 1992 the AMSAT V.P. for Manned Space developed the AMSAT SAREX Operations Team. This team is comprised of a contingent of AMSAT volunteers from around the world. The primary goal of this team is to provide coordinated technical support for SAREX over the large spectrum of operations and coordination activities.

The breakdown of responsibility of AMSAT's SAREX Operations Team is shown in Figure 3. The team provides mentors who technically coordinate the SAREX selected schools, and provides a representative who supports the SAREX flight operations at the Johnson Space Center during each SAREX mission. In addition to these activities, the team staffs the worldwide network of telebridge stations; they disseminate SAREX-related information before, during, and after the flight; and they are responsible for the distribution of the QSL cards. As shown, John Nickel, WD5EEV, is Frank Bauer's assistant. As such, he coordinates some of these activities and acts on Frank's behalf in his absence. In particular, John manages the telebridge support



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Figure 3. AMSAT SAREX Operations Team

and QSL distribution. John and Karen Nickel, (WD5EEV and WD5EEU respectively), also provide critical flight operations support for various SAREX missions. The following paragraphs highlight some of the operations team activities and describe some of the changes since Reference 4 was published.

Information Dissemination

Timely, accurate information is critical during short duration Space Shuttle missions with SAREX on-board. Stale Keplerian elements result in incorrectly pointed OSCAR antennas. This leads to missed contacts. Also, primary payload issues can result in a significant shift in the secondary payload mission (SAREX) timeline. General QSO voice and packet operations will be impacted as a result. Backup school group contacts sometimes are cleared for general QSO operations with less than 24 hours notice. This information needs to get to the ham community. The SAREX team relies on several information dissemination methods to get timely information to the users. In particular, the AMSAT.ORG mail exploders *SAREX* and *ANS* are used during the flight to post up-to-the-minute bulletins on SAREX, to provide the latest orbital elements and to provide Rise and Set times for those without orbital prediction programs. The above information can also be obtained via Internet on the Spacelink BBS: *spacelink.msfc.nasa.gov* or via the GSFC ARC BBS: *wa3nan.gsfc.nasa.gov*.

The SAREX World-Wide-Web home page is another excellent source of information. This home page, which is currently being restructured, will include information on upcoming SAREX missions and it includes several SAREX-related photos. Currently, there are photos depicting the SAREX flight hardware, a typical SAREX school group station and some photos of school students

talking to Jerry Linenger on STS-64. There are also some audio clips of a school group contact. The URL for the SAREX home page is: http://www.nasa.gov/sarex/sarex_mainpage.html.

Another key information dissemination source is the Goddard ARC shuttle retransmission station WA3NAN. In addition to the latest orbital elements, WA3NAN transmits SAREX bulletins and telebridge school group contacts while they are in progress.

Telebridge Enhancements

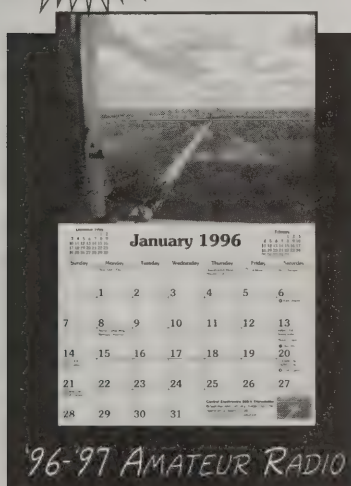
The telebridge system consists of an international network of Shuttle ground stations which can be linked to school groups using a telephone conferencing system (Figures 4 and 5). The telebridge system is used when direct Shuttle communications are impractical; possibly due to a low inclination orbit, lack of satellite operations experience at the school, or due to rise/set time scheduling conflicts between the school group and the Shuttle crew. As part of this activity DAROME Telecommunications in Chicago provides the vital telebridge communications link between the astronauts and the school. DAROME has provided this service to the SAREX team since the inception of the telebridge concept on STS-35 in 1990.

Several enhancements have been made to the telebridge system in the past two years. In particular, two new areas that have been added to augment the telebridge capabilities—South Africa and one high latitude area in the U.S (Figure 5). Hans van de Groenendaal, ZS5AKV, and Gerald Klatzko, ZS6BTD, have graciously donated their services to the SAREX cause in South Africa. In California, several Amateur Radio enthusiasts, including Tim Bosma, AB6FL, and Steve Teegarden, WH6IC, had a vision to develop a premier telebridge station in a high latitude region of the U.S. They

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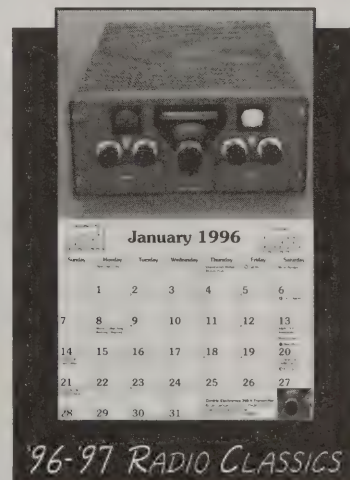
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convinced the staff at the Santa Rosa Junior College, Santa Rosa, California, particularly Randy McNally, the assistant dean of instruction, that the bridge station could become a significant educational resource to the school. They were then able to raise over \$30,000 in donations to install the telebridge station at the school. The facility includes a state of the art bridging system and an OSCAR satellite station. It also retransmits the Space Shuttle air-to-ground communications on Voice and ATV and provides amateur satellite demonstrations to middle and elementary school students. This premier facility is currently operational and available for all future SAREX missions. Their recent ribbon cutting ceremony attracted a great deal of media coverage from the San Francisco Bay Area.

Over a period of several years, one would expect some changes in telebridge ground stations and ground station support resulting from relocations, career changes, and lifestyle changes. As such, there have been several changes in our bridging support. Steve Teegarden's relocation from Hawaii to California resulted in the enlistment of Rich Weigand, AH6MC, to support Dick Flagg, AH6NM, in Hawaii. In addition, Ralph Warner started school in Los Angeles and could not support future SAREX missions in Southern California. Ron Earl, W6TXK, and Kerry Banke, N6IZW, were therefore recruited as bridge stations in San Diego. Another addition to the SAREX telebridge team is Bob Diersing, N5AHD, who has supported several missions from the Texas A&M facility in Kingsville, Texas. All these changes and additions are reflected in Figure 5.

School Group Mentoring

AMSAT's international team of operations volunteers, initially formed in October 1992, have done a superb job in making sure the schools are technically ready for their contacts. Each school group is now assigned a technical mentor, who is familiar with satellite communications. The primary responsibility of this mentor is to provide guidance in the school technical setup, to be on-hand for any questions or problems, and to be a conduit for vital information before, during and after the contact. In addition, technical guides, similar to the educational guideline material provided to the schools by the ARRL are distributed to the school contact coordinator. Frequent (weekly or biweekly) meetings/telecons are held with the operations team to ensure they have the latest information and are

progressing with their schools. As a result of these efforts, the technical support to all school groups has been considerably enhanced. Since its inception, the success rate with the schools has soared from 66-75% in 1992 to over 90% in 1994. On the most recent SAREX flights (STS-70 & 74) the team achieved its first missions with 100% success. A higher success rate provides the general Amateur Radio community additional opportunities to have QSOs with the astronauts because backup contacts, not required due to a successful prime contact, are usually cleared for general voice and packet QSOs. The AMSAT-NA would like to thank its SAREX Operations Team for their outstanding support and dedication in making these school contacts such a huge success.

The AMSAT team is also developing several SAREX resource guides including a 35mm slide set and a written publication. The written guide will include a compilation of information on past SAREX flights and will help School Group Coordinators prepare for their SAREX contacts.

QSL Cards

A unique QSL card is developed for each SAREX mission. Members of the ARRL Educational Activities Department (EAD), particularly Bob Inderbitzen, NQ1R, works with the astronauts to obtain mission photos and lay out the cards. Next, ARRL contracts with a printer for producing the QSL cards. Hams who make contact with the astronauts or hear their downlink are requested to send their cards (with an SASE) directly to the ARRL EAD with the mission number on the front of the envelope. These cards as well as the blank QSL cards are sent to the volunteer organization that distributes the cards. It is AMSAT's job to ensure a timely distribution of the QSL cards. John Nickel, WD5EEV, coordinates the distribution of the cards. A specific volunteer group is selected for each mission to distribute the cards. These volunteers provide a valuable service to ham radio operators, to the astronauts and to the SAREX team and their support is extremely appreciated. The cards are usually completely distributed within 2 months after receipt of the cards. To date, all the QSL cards for missions up to STS-67 have been distributed. Figure 6 represents a sample QSL card from the STS-64 mission. Table 3 lists the groups that have volunteered to distribute the QSL cards since 1993.



Figure 4. Telebridge Communications Link

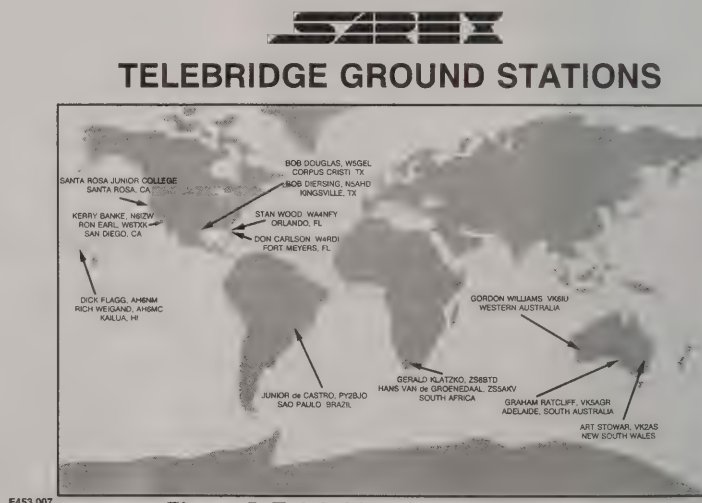


Figure 5. Telebridge Ground Stations

Frequency Coordination

AMSAT has worked with the ARRL and members of the IARU to help coordinate the SAREX frequencies at the international level. The SAREX frequencies chosen at the beginning of 1993 have had some success (Table 4). However, it has become increasingly difficult to find clear frequencies to use during the school group contacts. The lack of national-level frequency coordination for packet radio has made SAREX operation quite challenging to near impossible in some areas of the U.S. On every SAREX flight, the AMSAT technical mentors have to go to great lengths to research where potential clear frequencies exist at *each* school area and feed this information to the working group. From our extensive worldwide experience, we have found that packet operation is splattered throughout the two-meter band with no coherent bandplan. It, therefore, becomes difficult to impossible for the SAREX team to pick specific school group frequencies which can be used over much of the U.S.

In addition to the above, the Working Group has received post-flight complaints from the Astronauts regarding packet interference on the SAREX voice uplink frequencies. The astronaut concerns and some concerns raised by the European ham community regarding the 145.55 downlink frequency have resulted in an extensive review of the 2-meter bandplan and recommendations for new frequencies. Some of these frequencies were used for the first time on STS-71. In the near future it is hoped that these will be used by all manned spacecraft (Space Shuttle, ISS, and MIR) on 2 meters. Note that these new frequencies do not help the school group frequency problems. Only a coordination of packet radio frequencies at the national level will alleviate this problem. A concerted effort should be initiated to develop a nationally recognized coordinated bandplan for packet, similar to the successful repeater bandplan that is now in place.

The following new manned spaceflight frequency bandplan has been presented to the AMSAT/ARRL team as well as several IARU consultants in the US and Europe.

Manned Space Frequency Recommendations:

- 1) Worldwide Voice Operation on MIR and ISS:
Downlink 145.800 MHz
Uplinks 144.470 & 144.450 MHz
- 2) Worldwide Packet Operation on MIR and ISS:
Downlink 145.800 MHz
Uplink 144.490 MHz
- 3) A secondary downlink frequency of 145.84 is suggested to augment 145.80. This downlink will be used for Shuttle-type vehicles (such as the U.S. Space Shuttle) and for SAREX operations.
- 4) If a 600 kHz split pair is desired for Region 1 (Europe and Africa), the following is suggested:
Downlink 145.800 MHz
Uplink 145.200 MHz
- 5) The AMSAT V.P. for Manned Space Programs will work with IARU, ARRL and the U.S. Digital community in an effort to globally coordinate the above frequencies for manned space operations. Global coordination of all non confidential manned space frequencies for 15 meters, 10 meters and 70 cm is highly recommended and should be initiated.

Note that the above split mode frequency recommendations do not preclude simplex operations, if required. For simplex operations, the team will use frequencies which will minimize frequency contention such as 144.49 and 144.47, and 144.45.

1995 Mission Status

The SAREX team completed four missions in 1995 (Table 2). All were highly successful. The following represents highlights of these SAREX missions.



Figure 6. STS-64 QSL Card

STS-67

The STS-67 mission in March represented the longest space shuttle mission in history, 18 days. Six of the seven crew members on this flight were ham radio operators. These included Steve Oswald, KB5YSR, Bill Gregory, KC5MGA, Tammy Jernigan, KC5MGF, Wendy Lawrence, KC5KII, Sam Durrance, N3TQA and Ron Parise, WA4SIR (Figure 7). The flight included a record 26 schools which stretched the limits of all the volunteers who supported this flight; particularly the AMSAT school group mentors. Despite this heavy workload, this mission, from a SAREX perspective, was nearly flawless.

SAREX activity was a well balanced on this flight. It included packet radio operations, general voice QSOs, primarily by Ron Parise, school group contacts and personal communications between the crew their families. A total of over 2100 students were present during the shuttle radio linkups. Two noteworthy schools were the JJ Fray Elementary School in Rustburg, Virginia and the Little Lillies English School in Bangalore, India. Both schools had outstanding educational programs with significant coverage by the press. The JJ Fray School received letters of congratulation for their SAREX accomplishments from the President and Vice President of the United States and all the Federal and state congressional delegates from their area. They also received coverage in many magazines and papers including the Virginia Journal of Education, for example. The Little Lillies School received (and continues to receive) significant television and printed media coverage by all the major networks and papers in India. Moreover, the school group coordinator, Raj Ramesh, VU2RMS, has recently been awarded India's Rajiv Gandhi Foundation Award. This most prestigious award was personally given to Mr. Ramesh by Sonia Gandhi, the wife of the late Prime Minister Rajiv Gandhi. Prior to the contact, the students studied Amateur Radio and astronomy and posed some pretty challenging astrophysics questions to Astronaut Tammy Jernigan.

STS-71

The STS-71 mission in June was the first Shuttle-MIR docking flight. The Russian-American flavor of this mission extended beyond the docking flight. Since there was an Amateur Radio station on MIR and SAREX on the Space Shuttle, amateur contacts on both vehicles were contemplated and successfully accomplished. Ham astronauts Charlie Precourt, KB5YSQ and Ellen Baker, KB5SIX, were an integral part of this historic flight. Precourt, in fact, piloted the Space Shuttle during the rendezvous and docking activity. (Another first for ham radio operators). Five

schools had an opportunity to talk to the shuttle crew during this flight including the Benbrook Elementary School in Benbrook, Texas, with Donna McKinney, N5WOE, at the helm and the Yessentuki School Number 3 in Yessentuki, Russia which was coordinated by Valery Agabekov, UA6HZ.

The astronauts and cosmonauts used both the SAREX equipment and the MIR equipment during this flight. A new SAREX configuration was developed for this and subsequent Shuttle-MIR missions—Configuration M. Configuration M consists of the 10 watt Motorola wide-band radio used by NASA to communicate with MIR and either a window mounted antenna or a payload bay antenna which were developed for MIR operations. As part of the experimentation on this flight, the performance of each antenna was tested through SAREX ground stations. Doug Loughmiller, G0SYX, in Surrey England; Gordon Williams, VK6IU, in Australia; and Stan Wood, W4NFY, and Lou McFadin, W5DID, in Orlando Florida supported these tests.

STS-70

Just a few days after the STS-71 landing, the STS-70 mission commenced despite its one month delay due to woodpeckers that poked holes in the external tank insulation. Ham astronauts Don Thomas, KC5FVF, and Nancy Sherlock Curie, KC5OZX provided the SAREX team with a truly outstanding mission. The

following bulletin, uplinked to the crew for the SAREX team on the last day of the flight, truly sums up this mission.

STS-70 Uplink on Flight Day 8:

The SAREX team wishes to congratulate the 18th SAREX crew for an outstanding job. We hope you enjoyed the eight school contacts. By our calculations, you have talked to 291 students (1523 people in attendance) and answered 91 of their questions. You have conversed with over 400 hams by voice and 771 by packet.

It is an incredible feeling to see all the hard work come together and perform flawlessly on this mission. The Amateur Radio community, the school groups, ARRL, and AMSAT express their deep gratitude to you for all you have done. The schools send a Buckeye thanks (Note: all but one crew member had roots in Ohio). Your new friends in Argentina (one of the school groups) send their regards. Your ham contacts have already started sending in their QSL cards and are asking when you might fly again.

Your efforts allow us to ride along side you. Your superb answers to school childrens' questions provide the inspiration for the future astronauts of our small blue planet. You have made this a truly educational experience for all of us.

Thank you for a job well done. 73 de SAREX.



Figure 7. Ron Parise, WA4SIR, with SAREX hardware on STS-67

The second MIR docking flight, STS-74, was successfully completed in November. This was the final Space Shuttle and SAREX flight of the year. As he has done on previous flights, Commander Ken Cameron, KB5AWP, made sure his entire crew was licensed. Five Space Shuttle Astronauts, Commander Cameron, Pilot Jim Halsell, KC5RNI, Mission Specialist Bill McArthur, KC5ACR, Mission Specialist, Jerry Ross, N5SCW, and Canadian Mission Specialist Chris Hadfield, KC5RNJ (VA3OOG), provided one of the more outstanding, well rounded SAREX missions ever. The Shuttle crew did not waste any time getting on the air. Within 7 hours after liftoff, they were making general QSO contacts and they kept the radio warm until late in the flight. KC5ACR was still making voice contacts less than 7 hours prior to landing. The SAREX team estimates that the STS-74 crew made about 100 general voice contacts per day. During the mission, the Atlantis astronauts completed 5 scheduled Amateur Radio contacts with students in the US. During these school group contacts, students asked 54 questions and more than 2300 students participated in the events.

Hardware Enhancements

There are several hardware upgrades in progress at this time. Lou McFadin is modifying a pico-packet TNC to include several SAREX enhancements over the current SAREX TNC. In particular, the SAREX software is being installed in the TNC. Adequate RAM has been incorporated to store all the SAREX robot contacts without requiring a download on the Shuttle laptop, and battery operation will allow the TNC to be powered up during Shuttle power conservation measures. It is expected that this hardware will be available for flight in the middle of 1996.

The ROBOT 1200C SSTV module was qualified and initially flown on STS-51F in 1985. Since that time, there have been substantial reductions in the size and weight of SSTV electronics. The Robot SSTV hardware is not flown very often due to its size and weight. The potential for a significant size and weight reduction, coupled with the fact that today's PC computers can send and receive SSTV signals with minimal, low cost hardware make SAREX SSTV an attractive operational mode. The SAREX team is currently working with several SSTV hardware experts to develop a small, low power, lightweight module for the Shuttle. Its size and weight should be comparable to today's packet module. It is hoped that this module will be available by the end of 1996 or early 1997.

Future SAREX Flights on the Space Shuttle

There are at least five SAREX flights planned for 1996 (Table 5). Three of these missions will be Shuttle-MIR docking missions—STS-76, STS-79 and STS-81. On two of these flights, STS-76 and STS-79, crew members Shannon Lucid and Jerry Linenger, KC5HBR, will leave the Shuttle for a long duration stay on MIR. During a recent meeting in Houston, a request was made by the SAREX Working Group which would allow the astronauts to make SAREX contacts (school group, general QSO and personal

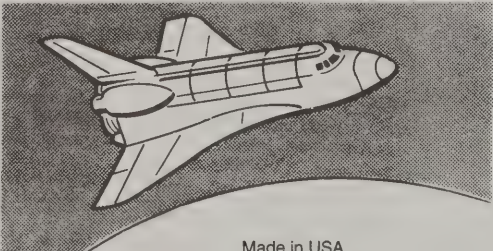
contacts) using the MIR radio. While there are several hurdles that need to be overcome to make this feasible, it could provide the SAREX Working Group a unique opportunity to validate some of the new operations techniques that we will need to put into practice on the ISS. The Working Group will continue its dialog with NASA and its Russian partners to support this unique opportunity.

International Space Station Plans

NASA will reach a continuous human presence in space in three discrete steps. The first is through joint U.S. Russian missions where U.S. Astronauts will spend extended periods of time (on the order of 90 days) on the Russian Space Station MIR. This activity was initiated in 1995 with Norm Thaggard's visit to MIR and the STS-71 MIR docking mission. This activity will continue until 1997. As the ISS is being assembled, from 1997 to 2002, *human-tended* operations represent the second discrete step in the NASA program. During this phase of the ISS development several week duration operations in the ISS laboratory module with a docked Space Shuttle will become the norm. Finally in 2002 the habitation module will be installed and permanent crew presence on the ISS will begin.

After reviewing the future shuttle flights, it becomes increasingly apparent to focus future SAREX activities toward a permanent presence in space. If one were to ponder the probability of amateur activities in space, one would quickly realize that *permanent presence* is the International Space Station.

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The SAREX team picks flights based on many criteria, but the major variables in the SAREX manifest are the attitude timeline and primary mission of each shuttle flight:

Shuttle/MIR docking missions have a busy timeline, many flight maneuvers, minimal school activity (5 schools or less), and some random QSO activity. The same goes for *early assembly flights*, which will look very similar.

Laboratory flights use a stable shuttle attitude and consistent activity level. These are ideal SAREX conditions. These flights can have more school contacts, more random QSO's, packet operations, and even time for experimentation.

Midway through the assembly flights (at the human-tended operations milestone) there will be packet, regularly scheduled school contacts, and random QSO's because of less restrictive timelines. These flights are similar in activity levels with the MIR station.

After the habitation module is launched, our permanent presence will facilitate more school contacts, random QSO's, experiments, demonstrations, earth observation downlinks, etc.

SAREX will:

- **Serve** as an educational tool,
- **Be** an outreach to the general public,
- **Allow** a method for crews to maintain contact with family and friends while on orbit (to improve psychological factors),
- **Provide** an experimental communications testbed,
- **Offer** a back up communications link for emergencies,
-
- **Provide** public information to the grass-roots public.

SAREX Equipment Strategy

While focusing on the new home for SAREX, we must not forget what got us where we are today. The plan is to gradually phase SAREX operations to a permanent station inside the ISS habitation module in the year 2002.

The first step SAREX will take is to update/upgrade the equipment currently used onboard shuttle missions (some of the upgrades were mentioned previously). SAREX currently has six different configurations (including the non-SAREX hardware configuration) which provide us with 2-meter frequencies at 2.5 watts, a 1200 baud TNC which counts *connects*, a slow scan module, a fast scan (ATV) module, a 2-meter/70cm cavity antenna, a 70cm loop antenna, and numerous interface cables. Upgrades would include a dual bander (2m, 70cm) radio; an expanded TNC (pico packet with more memory and BBS); a better, smaller slow scan module; and a battery charger.

At the same time, SAREX will utilize the unique opportunity of having US hams onboard the Russian space station MIR to develop and refine procedures & equipment

that will also be used aboard the ISS. MIR already has a 2-meter station onboard, but has plans to add new capabilities to the station in the near future (see Euromir ANS bulletin and Nov/Dec issue of *The AMSAT Journal*).

Next, SAREX will utilize the upgraded, portable equipment during *early ISS assembly flights*, which start in late 1997. Current, tentative plans include SAREX operations and permanent stowage as early as the second assembly flight. SAREX equipment during this time period has the distinct possibility of operating on both vehicles. Changes in the cavity antenna's adapter plate will be sought to use Earth viewing windows on the partially assembled space station. The equipment will be upgraded to include a radio and TNC capable of higher baud rates.

During later assembly flights (1998), SAREX will explore opportunities to mount a steerable antenna on the ISS truss to provide the capability to work other spacecraft and satellites (i.e., Phase 3D). SAREX will attempt to upgrade the portable equipment one last time before the permanent station is delivered in its module.

Finally in 2002, the habitation module will be delivered. The SAREX team is working hard to ensure that an external Earth viewing antenna; and a rack mounted transceiver capable of many new modes and frequencies will be part of the module with the capability for future expansion.

SAREX Development Strategy

When do we start? The answer is **NOW**. The working group has prepared paperwork to *become officially manifested*. The ISS design and its outfitting are maturing at a rapid rate. We must ramp up our effort on the habitation module station design. Work has begun on the scarring requirements for the permanent station. We must explore the real estate for our steerable antenna. We must design for future expansion. We must make the portable equipment

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usable on both vehicles. We must use the lessons learned from our past flights.

Lastly, SAREX will seek to combine efforts with the International Partners who are helping forge the ISS. We must keep SAREX an international venture. We must coordinate Amateur Radio activities in European, Japanese, and Russian modules on the ISS. This will enhance the overall ISS Amateur Radio *presence* and capability.

Third Party Restrictions

As the U.S. space program merges its activities with the international community, particularly Russia, the SAREX program is quickly doing the same. Amateur Radio has always shared an international camaraderie with our neighbors across the waters. This camaraderie has resulted in international partnerships which have extended to new heights...outer space. The most recent international space station collaboration is resulting in a quick blurring of the separate U.S. and Russian Amateur Radio activities on the U.S. Space Shuttle and the Russian space station MIR into a single Manned Space activity. These changes have brought new challenges to the SAREX team; that of ensuring a strong, well balanced program on an evolving manned platform while maintaining and adapting the international regulations regarding international Amateur Radio communications. Third party restrictions between Russia, the U.S. and other countries have been a problem for the SAREX and MIR teams this past year. As more countries become active partners in the international space station, this issue will get worse. Unfortunately, these restrictions curtail the amateur community's ability to spark student's interest in Amateur Radio by not allowing some astronauts (on international space carriers) and some foreign space participants to talk to students while in space.

The SAREX team is actively working with our international partners, particularly Russia in an attempt to get a permanent waiver of third party traffic restrictions to manned space vehicles. This would go a long way in improving international participation in Amateur Radio.

Conclusions

Human-operated ham radio in space appears to be transitioning from short, intense bursts of activity (analogous to a DXpedition) to permanent (nearly continuous) operations. Multiband, multi-mode operation and regularly scheduled school group contacts will be the norm in this scenario. While *cautiously optimistic* in an era of government budget cuts, the SAREX team will put forth its best efforts to ensure these dreams will become a reality for terrestrial based radio amateurs and ham radio operators in space.

While it continually maintains an eye towards the future, the SAREX team strives to improve the on-going

Shuttle-based SAREX activities. SAREX is an outstanding, low cost outreach program for Amateur Radio, NASA and science and technology. It could only be accomplished through the superb support from the hundreds of volunteers from around the world and the support, interest and encouragement from NASA, particularly the Astronaut Office and Division of Education at NASA Headquarters. The authors extend their deepest thanks to all these volunteers and especially to outgoing Principal Investigator Lou McFadin, W5DID, for their tremendous support to bring space-borne Shuttle astronauts literally into the schools and living rooms of the general public.

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P220VDA	220-225	< 1.2	15	0	DGFET	\$37.95
P220VDG	220-225	< 0.5	20	+ 12	GaAsFET	\$79.95
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SP144VDG	144-148	< 0.55	24	+ 12	GaAsFET	\$109.95
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SP220VDA	220-225	< 1.3	15	0	DGFET	\$67.95
SP220VDG	220-225	< 0.55	20	+ 12	GaAsFET	\$109.95
SP432VD	420-450	< 1.9	15	-20	Bipolar	\$62.95
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Appendix A SAREX Contact Guidelines

1. The deadline for school group applications for a particular mission will be set a launch minus seven and a half months (L-7.5). Final school selection will be made at L-7.

2. No school groups will be considered for a SAREX contact unless a fully completed application is received by the ARRL (American Radio Relay League) before the deadline set for that particular mission. Proposals are also encouraged but do not take the place of an official application.

3. In an effort to geographically diversify the SAREX contacts, there will be no more than two school contacts from the same state on one specific mission.

4. To maintain fairness to those schools seeking a SAREX contact, repeat contacts with school groups/school districts should be discouraged whenever possible. (ARRL does have a waiting list already)

5. The selection of schools should be based on the application/proposal submitted by the school group. The following criteria should be used to evaluate the schools:

a) Educational program including the school's ability and/or knowledge to carry out such a plan. (Note, this criteria carries the most weight in the selection process).

Table 1. SAREX Missions Flown to Date 1983-1993

Flight	Date	Amateur Radio Crew		Modes
STS-9/Columbia	November, 1983	Owen Garriott, W5LFL		Voice
STS-51F/Challenger	July, 1985	Tony England, W0ORE	John-David Bartoe, W4NYZ	Voice, SSTV
STS-35/Columbia	December 1990	Ron Parise, WA4SIR		Voice, Packet
STS-37/Atlantis	April 1991	Ken Cameron, KB5AWP Linda Godwin, N5RAX Jerry Ross, N5SCW	Jay Apt, N5QWL Steve Nagel, N5RAW	Voice, Packet, ATV Uplink
STS-45/Atlantis	March 1992	Dave Leestma, N5WQC Dirk Frimout, ON1AFD	Brain Duffy, N5WQW Kathy Sullivan, N5YYV	Voice
STS-50/Columbia	June 1992	Dick Richards, KB5SIW	Ellen Baker, KB5SIX	Voice, Packet SSTV, ATV Uplink
STS-47/Endeavor	September 1992	Jay Apt, N5QWL	Mamoru Mohri, 7L2NJY	Voice, Packet
STS-56/Discovery	April 1993	Ken Cameron, KB5AWP Mike Foale, KB5UAC Steve Oswald, KB5YSR	Ken Cockrell, KB5UAH Ellen Ochoa, KB5TZZ	Voice, Packet SSTV, ATV Uplink
STS-55/Columbia	April 1993	Steve Nagel, N5RAW Charlie Precourt, KB5YSQ Ulrich Walter, DG1KIM	Jerry Ross, N5SCW Hans Schlegel, DG1KIH	Voice, Packet
STS-57/Endeavor	June 1993	Brian Duffy, N5WQW	Janice Voss, KC5BTK	Voice, Packet
STS-58/Columbia	October 1993	Bill McArthur, KC5ACR Rick Searfoss, KC5CKM	Marty Fettman, KC5AXA	Voice, Packet

b) Amateur radio activities initiated prior to the SAREX contact and planned after the completion of the SAREX contact.

c) Technical ability of the group to set up an adequate station and successfully complete the SAREX contact.

6. The SAREX configuration for a specific mission will be discussed and decided with the crew at the Flight Planning and Storage Review (L-8). A list of the number and type of all planned crew selected activities (personal, school and experimental) shall be provided by the crew at the start of crew training. SAREX will provide the preliminary requirements to the Flight Activities Officer (FAO) at approximately L-7. An initial pass list (from FAO) shall be provided to SAREX at L-6. SAREX shall provide the final

requirements by L-5. The final pass list shall be supplied to SAREX at L-4.

The total number of contacts that can be accommodated on a specific mission shall be determined based on negotiations with ARRL, Radio Amateur Satellite Corporation (AMSAT), Space Shuttle Program (SSP), NASA Headquarters Education Division (Office of Human Resources and Education), and the flight crew. There will be one SAREX radio check scheduled as the first SAREX contact. In addition, the total number of scheduled SAREX school and experimental activities, excluding personal flight crew contacts, shall not exceed an average of 2 per day for the duration of the mission. Crew recommendations will be carefully considered for final selection of schools to be contacted but should not exceed

Table 2. SAREX Mission Flown to Date 1994-1995

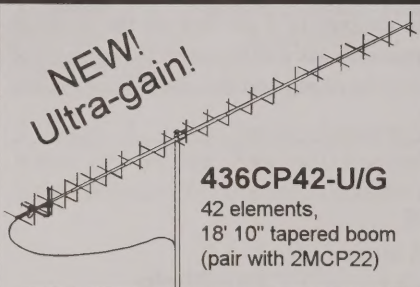
Flight	Date	Amateur Radio Crew		Modes
STS-60/Discovery	February, 1994	Charlie Bolden, KE4IQB Sergei Krikalev, U5MIR	Ron Sega, KC5ETH	Voice, Packet
STS-59/Endeavor	April, 1994	Jay Apt, N5QWL	Linda Godwin, N5RAX	Voice, Packet
STS-65/Columbia	July 1994	Don Thomas, KC5FVF	Bob Cabana, KC5HBV	Voice, Packet
STS-64/Discovery	September 1994	Dick Richards, KB5SIW Jerry Linenger, KC5HBR	Blaine Hammond, KC5HBS	Voice, Packet,
STS-67/Endeavor	March 1995	Steve Oswald, KB5YSR Bill Gregory, KC5MGA Tammy Jernigan, KC5MGF	Ron Parise, WA4SIR Wendy Lawrence, KC5KII Sam Durance, N3TQA	Voice, Packet
STS-71/Atlantis	June-July 1995	Charlie Precourt, KB5YSQ	Ellen Baker, KB5SIX	Voice
STS-70/Discovery	July 1995	Don Thomas, KC5FVF	Nancy Curie, KC5OZX	Voice, Packet
STS-74/Atlantis	November 1995	Ken Cameron, KB5AWP Bill McArthur, KC5ACR, Chris Hadfield, KC5RNI, VA3OOG	Jim Halsell, KC5RNI Jerry Ross, N5SCW	Voice

Table 3. SAREX QSL Volunteer Organizations

Mission	Date	Organization	Coordinator
STS-56	April 1993	Vienna Wireless Society	Chris Bayus, KD4FBU
STS-55	April 1993	IBM Amateur Radio Club	Neal Osborn, N4PYB
STS-57	June 1993	Miami County ARC	Marvin Force, KB8MUV
STS-58	October 1993	ARRL/Connecticut DX Association	Peter Budnick, KB1HY
STS-60	February 1994	Cowley County Amateur Radio Club	Karen Nickel, WD5EEU
STS-59	April 1994	Orange Park Amateur Radio Club	Dave Kalahar, KD4HXT
STS-65	July 1994	Lake County Amateur Radio Club	Charlie Sufana, AJ9N
STS-64	September 1994	Nashua Area Radio Club	Joel Levin, KD1ON
STS-67	March 1995	Edison Radio Amateur Association	Brian Westphal, KB8QXA
STS-71	June 1995	Sacred Hearts Academy Radio Club	Dick Flagg, AH6NM
STS-70	July 1995	Sterling Park ARC	Dick Maylot, W4LMJ
STS-74	November 1995	Greater Norwalk ARC	Ray Hilson, WB1U

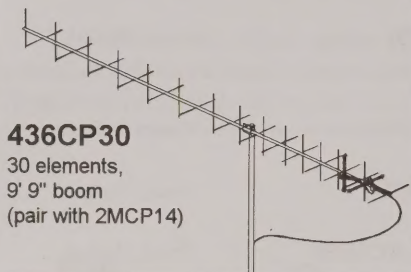
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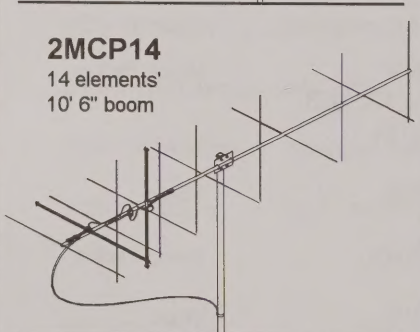
436CP42-U/G

42 elements,
18' 10" tapered boom
(pair with 2MCP22)



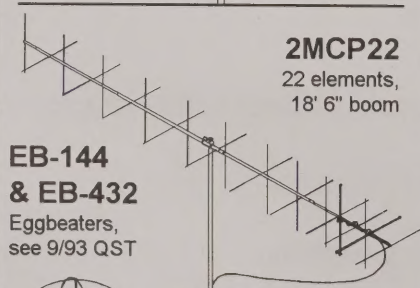
436CP30

30 elements,
9' 9" boom
(pair with 2MCP14)



2MCP14

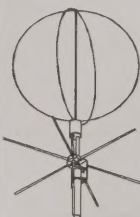
14 elements'
10' 6" boom



2MCP22

22 elements,
18' 6" boom

EB-144
& EB-432
Eggbeaters,
see 9/93 QST



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Table 4. SAREX Frequencies Chosen in 1993

		Europe	Rest of World
<u>Voice</u>	Downlink	145.55 MHz	145.55 MHz
	Uplinks	144.70 MHz	144.99 MHz
		144.75 MHz	144.97 MHz
		144.80 MHz	144.95 MHz
			144.93 MHz
			144.91MHz
<u>Packet</u>	Downlink	145.55 MHz	145.55 MHz
	Uplink	144.49 MHz	144.49 MHz

one-fourth of the total. Personal flight crew scheduled contacts will be limited to one per crew member. An adequate backup schedule shall be developed and included in the mission timeline.

7. The SAREX team will make every effort to minimize personal (family) contacts over the mainland U.S.

8. General contacts with the amateur fraternity are a vital facet of SAREX. The crew is highly encouraged to make voice or packet contacts with hams on the ground whenever possible.

9. When SAREX is left unattended during a flight, it is desired that the packet system shall be kept in robot mode as much as possible.

10. Backup contacts which are pre-scheduled into the timeline but not needed due to successful prime contacts may be used for general voice contacts with the amateur radio fraternity, if crew activities permit.

11 Mission Development and the SAREX program have established that nominally four SAREX flights should be manifested per year. This number is a SAREX target which can be increased or decreased from year to year based primarily on SAREX budgetary and resource constraints. ■

AO-13 Schedules 1996

Mode Schedule

N QST *** AO-13 TRANSPONDER SCHEDULE *** 1996 Jan 08 - Apr 01
 Mode-B : MA 0 to MA 140
 Mode-BS : MA 140 to MA 240
 Mode-B : MA 240 to MA 256
 Omnis : MA 250 to MA 100

Alon/Alat 220/0

Move to attitude 180/0, Apr 01

Please note that the higher powered engineering beacon 145.985 MHz is ON for the period: MA 0 - 40. (The lower powered beacon at 145.812 MHz is then off).

Errata

■ Ron Broadbent G3AAJ has asked that we clarify the notice appearing on pg 31 of the November/December issue of *The AMSAT Journal* titled *Still Time to Fly Your Callsign on Phase 3D*. The offer is open to any individual sending at least \$250 (≈ £150) or businesses, universities or government agencies sending \$8,000 (≈ £5000) to AMSAT-UK. Donors of the amounts specified will be provided with a photograph of the plate installed on Phase 3D and an engraved certificate or plaque.

■ Also the correct date for AMSAT-NA 14th Space Symposium and Annual Meeting is November 8-10, 1996 in Tucson, AZ. To learn more contact Larry Brown, NW7N (nw7n@amsat.org) or Heather Johnson, N7DZU (n7dzu@azstarnet.com).

Table 5. Future SAREX Flights

Mission	Launch	Length	Amateur Radio Crew	Inclination	Config.	Op. Modes
STS-76 MIR Docking Flt-3 Atlantis	3/21/96	9 days	Richard Searfoss, KC5CKM, PLT Shannon Lucid, TBD, MS Linda Godwin, N5RAX, MS Ron Sega, KC5ETH, MS	51.6	M	FM Voice
STS-78/LMS Columbia	6/27/96	16 days	Susan Helms, KC7NHZ, MS Charles Brady, N4BQW, MS Robert Thirsk, VA3CSA, MS Jean-Jacques Favier, TBD, MS	39	C	FM Voice Packet
STS-79 MIR Docking Flt-4 Atlantis	8/1/96	9 days	Jay Apt, N5QWL, MS Jerry Linenger, KC5HBR, MS	51.6	M	FM Voice
STS-80 Columbia	11/7/96	16 days	Ken Cockrell, KB5UAH, CDR Tammy Jernigan, KC5MGF, MS	28.5	C	FM Voice Packet
STS-81 Atlantis	12/5/96	9 days	To be determined	28.5	C	FM Voice Packet

Notes: CDR=Commander, PLT=Pilot, MS#=Mission Specialist, PS#=Payload Specialist

Satellite Orbital Elements

by Ray Hoad, WA5QGD

Satellite	AO-10	UO-11	RS-10/11	AO-13	FO-20	RS-12/13	RS-15
Catalog	14129	14781	18129	19216	20480	21089	23439
Epoch Time	96003.82203279	96003.52717005	96003.18510176	96002.80217352	96003.16062099	96002.87082824	96002.88615737
Element Set	397	852	154	129	873	856	113
Inclination	26.4182	97.7877	82.9245	57.4121	99.0494	82.9206	64.8162
RA of Node	230.6314	1.7395	271.2286	143.4822	059.4282	312.6784	292.0257
Eccentricity	0.5976999	0.0010583	0.0009985	0.7364528	0.0541100	0.0029544	0.0165538
Arg of Perigee	339.7618	260.7862	257.4534	27.9150	140.6269	340.2807	228.1333
Mean Anomaly	4.3050	99.2146	102.5505	356.8064	223.5497	19.7205	130.5347
Mean Motion	2.05882115	14.69414819	13.72360511	2.09726830	12.83232378	13.74064173	11.27523952
Decay Rate	-.00000137	.00000124	.00000028	-.00000136	-.00000040	.00000042	-.00000039
Epoch Rev	9443	63332	42740	5783	27569	24619	04203
Satellite	UO-14	AO-16	DO-17	WO-18	LO-19	UO-22	KO-23
Catalog	20437	20439	20440	20441	20442	21575	22077
Epoch Time	96003.77087703	96003.17523100	96003.14394705	96003.13030145	96003.13858167	96004.16923371	96002.94357072
Element Set	151	958	962	955	962	656	549
Inclination	98.5578	098.5706	098.5725	098.5701	098.5734	98.3743	066.0793
RA of Node	89.8108	091.1800	091.7027	091.6415	092.0787	75.2957	177.5323
Eccentricity	0.0011226	0.0011499	0.0011698	0.0012521	0.0012408	0.0008767	0.0005192
Arg of Perigee	333.8598	336.4578	335.7868	335.7984	335.0175	40.2073	345.3755
Mean Anomaly	26.2016	023.6078	024.2781	024.2608	025.0386	319.9762	014.7112
Mean Motion	14.29908290	14.29963084	14.30104708	14.30074639	14.30180177	14.37006660	12.86294676
Decay Rate	-.000000018	.000000018	.000000007	-.000000014	-.000000023	-.000000005	-.000000037
Epoch Rev	31041	31034	31036	31036	31028	23436	15942
Satellite	AO-27	IO-26	KO-25	NOAA-14	Phase JD (Est)	MIR	HUBBLE
Catalog	22825	22826	22828	23455	1	16609	20580
Epoch Time	96003.18971795	96003.12852178	96003.14868763	96003.84558255	91080.000000	96003.57982988	96004.18620137
Element Set	472	445	432	451	1	378	752
Inclination	098.6012	098.5976	098.5932	98.9244	98.9994	51.6446	28.4698
RA of Node	081.6137	081.6818	081.7508	309.9921	237.3099	233.8118	199.1414
Eccentricity	0.0009297	0.0009896	0.0010568	0.0010064	0.0013956	0.0006204	0.0005704
Arg of Perigee	001.6610	002.3747	347.6537	353.2351	238.3099	168.5622	253.5398
Mean Anomaly	358.4603	357.7480	012.4383	6.68685	121.6710	191.5522	106.4538
Mean Motion	14.27683524	14.27791326	14.28125408	14.11559416	14.13713945	15.57622987	14.90996683
Decay Rate	.000000007	-.000000014	.000000023	.000000057	.000000040	.00002269	.00000330
Epoch Rev	11830	11830	8641	5212		56419	11393

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OSCAR 13 Mode S Hardware: Mode S OSCAR 13 Downconverter, Mode S Parabolic 2'x3' Antenna

Rotors and Hardware: Yaesu G-5400B Az/EI Rotor, Yaesu Az/EI Rotor sep. kit, Emoto Rotors

OSCAR Satellite Antennas: M² 2MCP22 22 el. RHCP, M² 436CP42-U/G 42 el. RHCP, M² 2MCP14 14 el. RHCP, M² 436CP30 30 el. RHCP, M² EB-144 Eggbeater, M² EB-432 Eggbeater, M² GP for Eggbeater, KLM 2M-22C 22 el. and pol. switch, KLM 2M-14C 14 el. and pol. switch, KLM 435-18C 18 el. and pol. switch, KLM 435-40CX 40 el. and pol. switch

Crossbooms: M² Fiberglass 10 ft x 2 in (1-1/2 in. insert for G-5400B), KLM 5 ft x 1-1/2 in, 7.5 ft. x 1-1/2 in

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